EVALUATION OF THE PERFORMANCE OF ATTIC TURBINE VENTILATORS

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

[redacted]

EVALUATION OF THE PERFORMANCE OF ATTIC TURBINE VENTILATORS

February 1990

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FOREWORD

The project documented in this report received funding under the Innovative Housing Grants Program of Alberta Municipal Affairs. The Innovative Housing Grants Program is intended to encourage and assist housing research and development which will reduce housing costs, improve the quality and performance of dwelling units and subdivisions, or increase the long term viability and competitiveness of Alberta's housing industry.

The Program offers assistance to builders, developers, consulting firms, professionals, industry groups, building products manufacturers, municipal governments, educational institutions, non-profit groups and individuals. At this time, priority areas for investigation include building design, construction technology, energy conservation, site and subdivision design, site servicing technology, residential building product development or improvement and information technology.

As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied. Comments and suggestions on this report are welcome. Please send comments or requests for further information to:

Innovative Housing Grants Program
Alberta Municipal Affairs
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EXECUTIVE SUMMARY

Attic turbine ventilators are increasingly used in residential applications to remove heated air from attic spaces during summer periods and in turn to reduce the energy transfer between attic and living spaces. Concerns have been expressed as to whether increasing attic ventilation rates may produce problems of interior condensation at wall-ceiling intersections during periods of low ambient temperature. In many instances, purchasers tend to expect dramatic improvements in the comfort level of living spaces when an attic turbine ventilator has been installed.

A two-part study was undertaken to evaluate the operating characteristics of turbine type ventilators in the laboratory and their effect in a representative residential application. The laboratory studies indicated that in a wind tunnel, a 305 mm ventilator produced flows of 13.8 l/s per m/s of wind speed. This flow rate translates to a potential exchange rate of approximately 0.6 air change per hour (ACH) per m/s in the attic of an average 110 square meter bungalow, but is dependent on the actual attic construction and local sheltering.

A simple model of an attic was used to predict changes in ventilation rate with and without an attic ventilator installed in the test house. The model indicated that the turbine ventilator would enhance exchange rates on the order of 30 percent, but that any enhancement was dependent on the relative change in total attic ventilation area due to the installation of the ventilator.

Field experiments in a test house indicated flows through the attic ventilator approximately 2.5 times higher at any wind speed than those measured in a wind tunnel. It is thought that the increased flow through the ventilator installed in

the test house was due to different inlet and outlet pressure conditions than were present in the wind tunnel. Higher pressure differentials caused by flow acceleration over the roof and around the building result in increased flow through the ventilator.

Laboratory studies do not give enough information to predict the probability of moisture problems caused by the installation of a turbine attic ventilator. The simple attic model indicates that the installation of a single turbine ventilator should not result in a large enough increase in ventilation rate to result in interior moisture problems. Similarly, the model indicates that multiple ventilators installed on a roof would have little effect over that produced by a single ventilator.

Field measurements of attic ventilation rates with and without a turbine ventilator indicated that the enhancement provided by the ventilator was a function of wind direction, with the greatest benefit in the direction with the most upwind shelter. Ventilation enhancement ranged between 5 and 50 percent. Averaged over all wind directions and seasons, the turbine ventilator increased ventilation rates by approximately 15 percent from 5.3 to 6.1 air changes per hour.

Measured temperatures within the RSI 2.11 (R 12) ceiling insulation which projected out over the wall top plate indicated that the glass fibre used provided little resistance to air flow. The temperature within the insulation at locations over the wall was dependent on the ambient temperature, wind direction and speed. High wind speeds and low ambient temperatures reduced the effectiveness of the insulation and increased the potential for interior condensation due to localized interior surface temperatures below the dew point.

Interior condensation due to enhanced flow at the wall-ceiling intersection was not observed, nor was any evidence of condensation. Measured interior surface temperatures indicated that for typical interior conditions (20°C, 40% RH), the potential for condensation existed for 2 percent of the months of November and December.

Measured rates of heat transfer at ceiling locations near the wall-ceiling intersection showed that the effectiveness of ceiling insulation could be improved significantly with the installation of insulation stops. The cardboard stops prevent large amounts of air from moving through the insulation by directing it up and over the insulation.

1.0 INTRODUCTION

This study was undertaken in 1989 by the Department of Mechanical Engineering at University of Alberta to evaluate the effectiveness of turbine type attic ventilators in residential applications. Turbine ventilators are devices comprised of two parts - a base assembly which is fixed to the roof and centered over a hole through to the attic, and a rotating element constructed in a manner similar to a centrifugal fan. The rotating element or turbine head spins under the influence of air moving over the roof surface and, while spinning, draws hot air from the attic space. Removal of warm air in the attic space should result in greater occupant comfort during the summer months by reducing heat transfer to the living space.

The study was prompted by a relatively large number of enquiries received by Alberta Energy, Energy Conservation Branch concerning the effectiveness of the ventilators. In addition, some concerns regarding condensation problems within the living area of homes were expressed. Evidently under certain conditions, the volume of cold air drawn through soffit vents and exhausted through the ventilator was sufficient to cause cooling of the interior drywall surface at the intersection of the wall and ceiling. A sufficient drop in surface temperature could result in condensation of water vapour from the interior air resulting in moisture damage, or in extreme cases, the growth of mould and mildew. Although concern was expressed, no documented cases have been seen.

In addition to the questions above, it was hoped the study would also provide quantitative information on volumetric flow rate - wind speed relationships for this type of ventilator and clarify wind direction effects.

The study was undertaken in two parts. The first involved laboratory and wind tunnel experiments to calibrate flow measurement stations installed in the turbines and to obtain base line air speed versus flow relationships. The second part involved the installation of a ventilator on an instrumented house at the Alberta Home Heating Research Facility (AHHRF) and the measurement of attic ventilation rates and flow through the ventilator over a period of time. A site plan of the facility has been included in Appendix A.

2.0 LABORATORY STUDIES

The laboratory study was comprised of two parts - calibration of the flow meter installed in the base of the ventilator and measurement of flow rate through the ventilator when placed in a wind tunnel. The flow meter was installed in the ventilator so that measurements of actual flow under field conditions could be made. The measurements were then compared to attic ventilation rates determined using a separate tracer gas system. The comparison allowed accurate determination of the contribution of the ventilator to total attic ventilation rate.

2.1 Flow Meter Calibration

The flow meter installed in the base of each turbined ventilator is shown in Figure 1. The flow meter is an equal area averaging stagnation tube with a static pressure port located on the back side of the center hub. An averaging configuration was chosen so that accurate flow measurements could be obtained over a wide range of inlet conditions. The apparatus used to calibrate the flow meter is shown schematically in Figure 2. The ventilator was installed in a calibration box which was connected to a fan and a calibrated laminar element flow meter. The equipment was set up as shown in the figure so that air would be drawn through the base of the ventilator, into the box, through the laminar element flow meter and then exhausted through the fan. The setup allowed simulation of the base condition expected when the ventilator is installed on a roof with a large volume of essentially quiescent air within the attic. During calibration, the rotating element of the ventilator was free to turn so as to not to impede the flow.

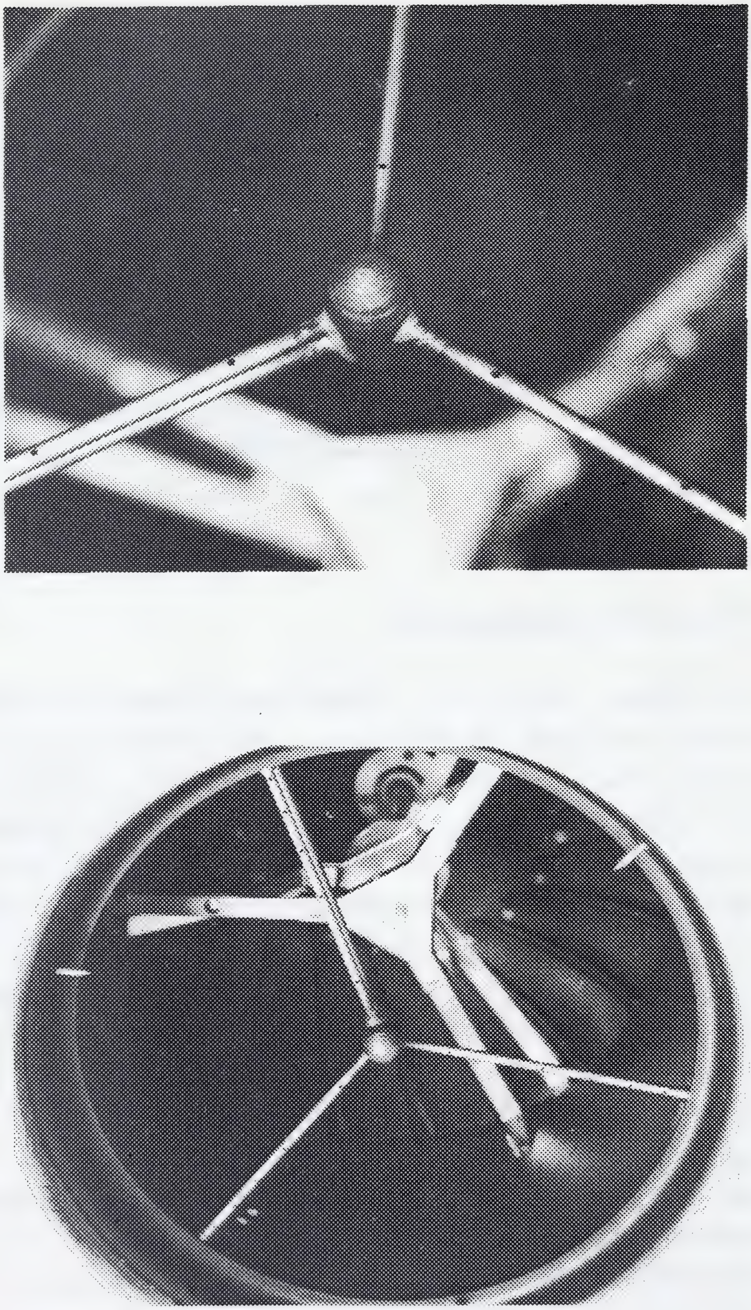


Figure 1. Close Up Photgraphs Showing a Flow Meter Installed in the Turbine Ventilator Base

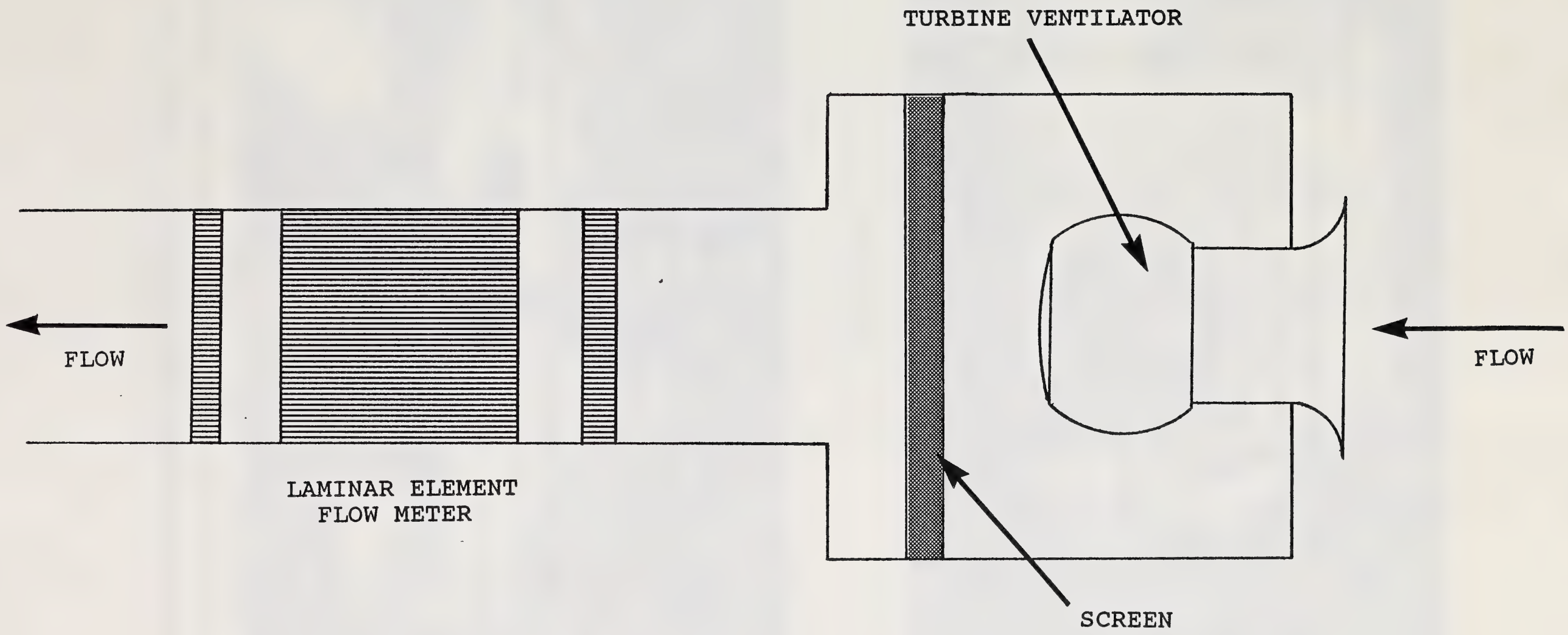


Figure 2. Schematic of System Used to Calibrate a Flow Meter Installed in the Base of a Turbine Ventilator

The pressure differential produced by air moving past the ventilator flow meter was measured using a calibrated low pressure transducer while volumetric flow rate through the test assembly was measured using a calibrated laminar element. In all cases, air was drawn through the base of the ventilator and through the calibration assembly. In no case was the flow reversed through the ventilator. Figure 3 shows the ventilator assembly installed in the calibration apparatus.

The flow meter installed in the base of the ventilator was calibrated over a range of 0 to 500 l/sec (0 - 1060 CFM) as shown in Figure 4. A working relationship, equation (1),

$$Q = C\Delta P^{n} \tag{1}$$

was fit with n and C determined using a least squares regression on the data. Using the working relationship with n, the flow exponent, equal to 0.51 and C, the flow coefficient, equal to 70.37, the volumetric flow rate through the ventilator in litres per second can be calculated. The three curves shown in Figure 4 may require some explanation. The center curve represents the results of the regression analysis, the working relationship $Q = C\Delta P^{n}$. The additional two curves show limits of error in measured flow rate of ± 5 percent and serve to gauge the accuracy of the working relationship.

2.2 Wind Tunnel Testing

Upon completion of the flow meter calibration, the ventilator unit was placed on a base and installed in the wind tunnel as shown in Figure 5.

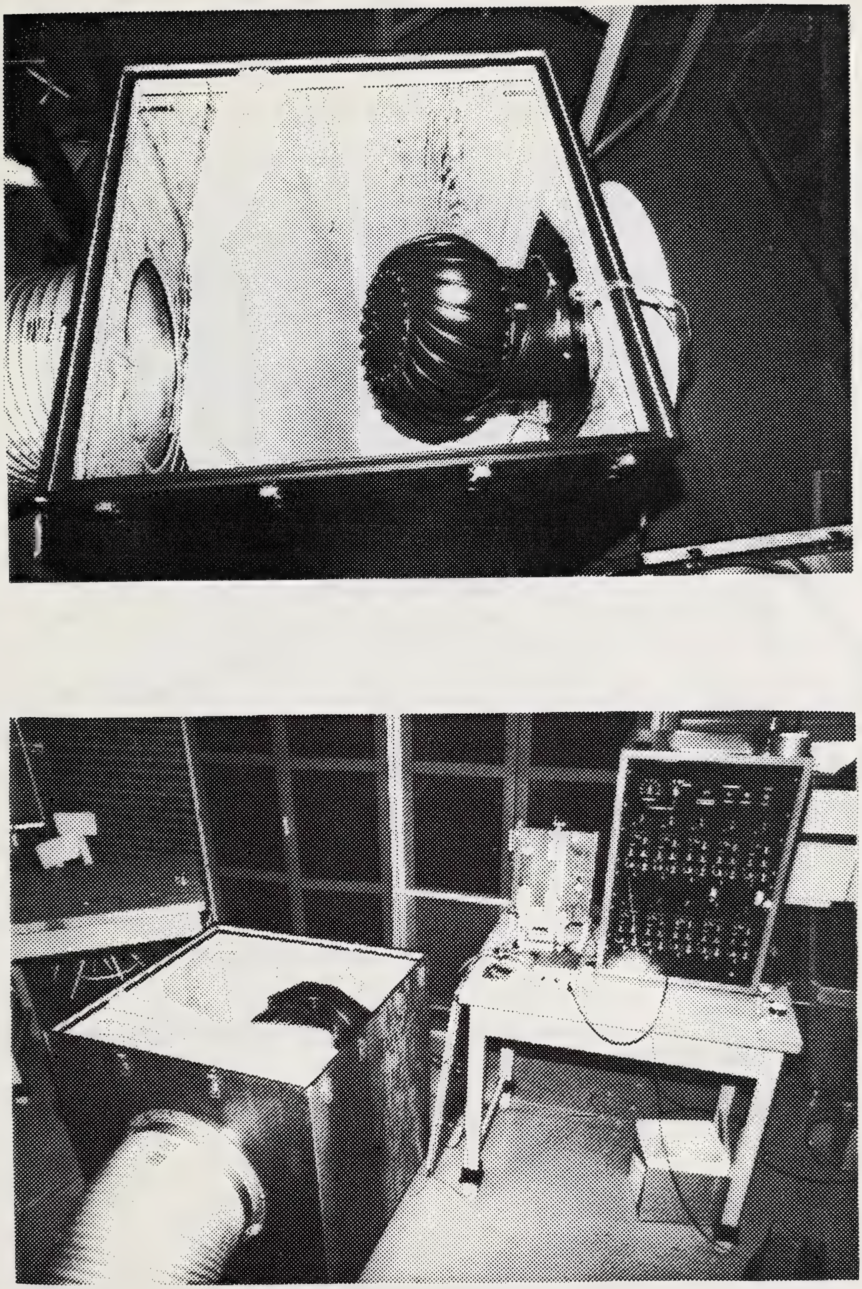


Figure 3. Photographs Showing a Turbine Ventilator Installed in the Flow Calibration System

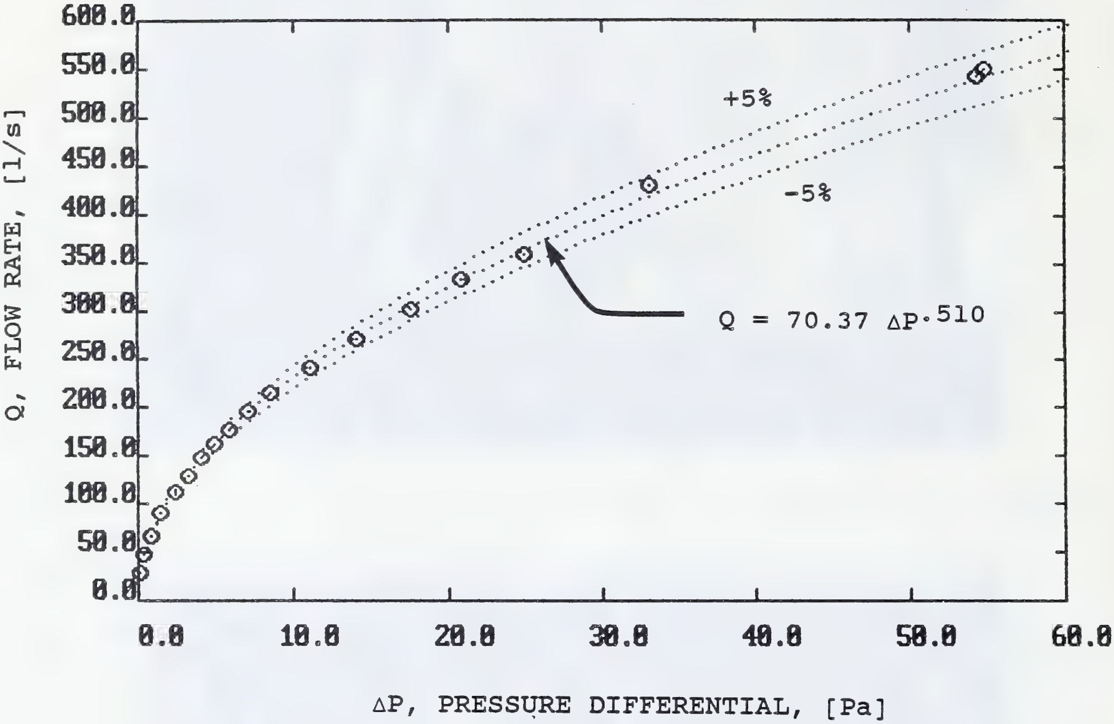


Figure 4. Calibration Curve for Averaging Pitot Tube Installed in the Turbine Ventilator

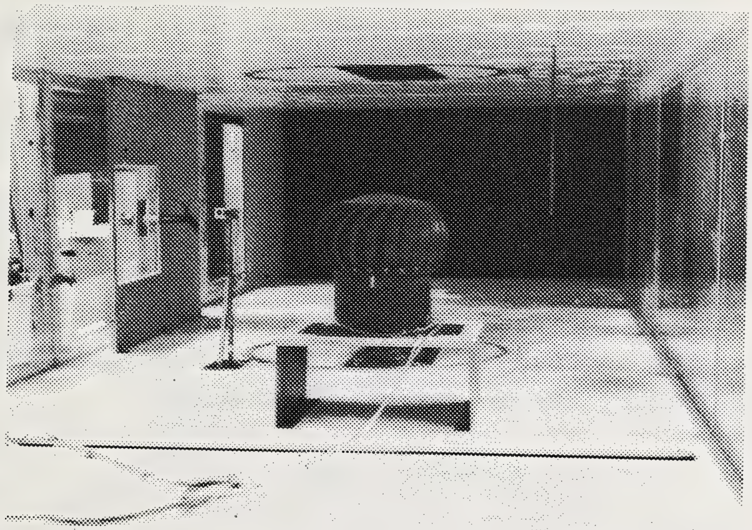


Figure 5. Photograph Showing a Turbine Ventilator Installed in a Wind Tunnel

The base assembly, as shown in Figure 5, allowed unrestricted air flow around the ventilator and below the inlet to the ventilator. The particular configuration was chosen so that the effect of the rotating element could be determined. It should be noted that the conditions seen by the ventilator while in the wind tunnel are unlikely to be the same as those in the field installation since no provision for unequal pressures above and below the ventilator was made. Flow rates were measured at wind speeds of 2 to 17 m/s (7-60 km/hr). The air speed range used produced flow rates of 25 l/s to 225 l/s (55-475 CFM) through the ventilator. The resulting data, plotted in Figure 6, show an approximately linear relationship between air velocity and flow rate which can be described by the following relationship:

$$Q = 13.77U - 0.136 \tag{2}$$

In this relationship flow rate, Q, has the units of litres per second and air speed, U, meters per second. Although not examined in detail, the rotor starting threshold appeared to be near 1.5 m/sec.

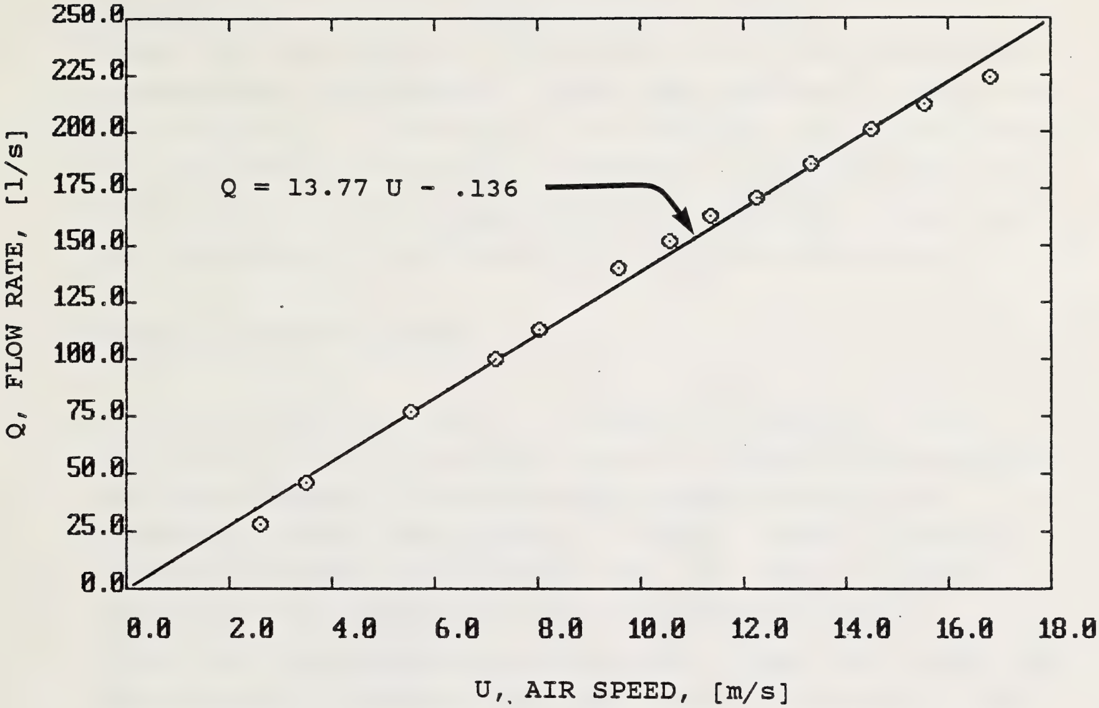


Figure 6. Calibration Curve Obtained with Ventilator Installed in a Wind Tunnel

3.0 PREDICTED ATTIC VENTILATION RATES

The prediction of attic ventilation rates with or without an attic ventilator installed is a complicated problem since very little is known about the conditions in or near the attic space. Flow paths, flow path resistance and pressure differences inside and outside the attic are all unknowns. In addition, the structure may be sheltered by surrounding buildings or terrain on one or more sides leading to further complications in the flow around the building and in the derivation of an accurate model.

3.1 Simplified Attic Model

One may, however, look at a simplified model of attic ventilation and in so doing obtain a better understanding of the potential a turbine ventilator may have for enhancing attic ventilation. Figure 7 shows a generic attic in a house with a gable roof and vented soffits. Assuming, for simplicity, that the wind is from a direction perpendicular to the line of the roof peak, one can imagine a general flow path through the attic. Flow entering the upwind soffit and exiting through the downwind soffit would be regulated by the pressure distribution surrounding the attic and the flow path resistance. The physical system may be described by an electrical analogy, Figure 8, in which voltage drop would represent the upwind - downwind pressure differential, resistance would represent the characteristic of the soffit to impede flow, and current would represent air flow. The electrical analogy for the attic with no ventilator would simply be two resistances in series.

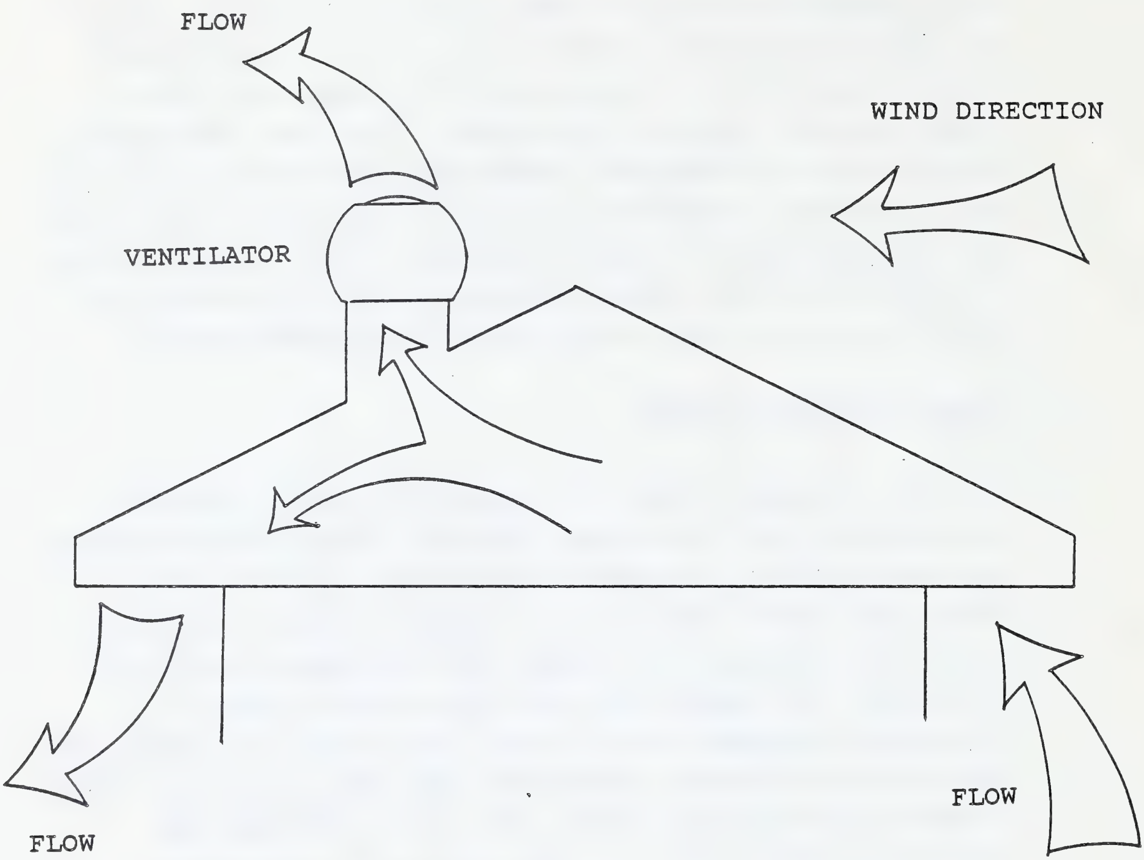
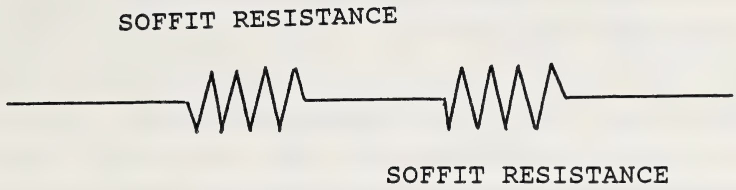
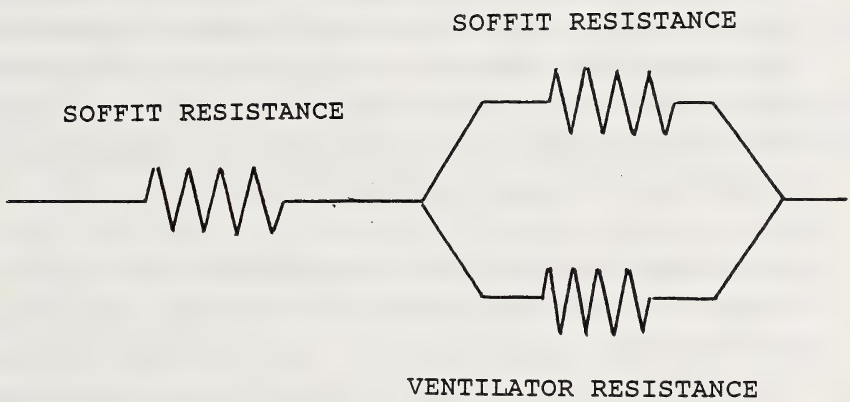


Figure 7. Schematic of Attic Showing Generalized Air Flow



a) NO VENTILATOR



b) VENTILATOR INSTALLED

Figure 8. Electrical Analogy of Flow Through an Attic With and Without a Turbine Ventilator

The analysis is slightly more complicated since flow through sharp edged holes, such as the perforations in soffit material, is not directly proportional to pressure differential across the hole but to the square root as indicated below:

$$Q = C\sqrt{\Delta P} \tag{3}$$

When the ventilator is present, the electrical analogy becomes more complicated as there are two flow resistances in parallel, the ventilator and the downwind soffit, and these two are in series with the resistance due to the upwind soffit. The electrical analogy for this configuration is also shown in Figure 8. Since one soffit and the ventilator are in parallel, an equivalent resistance can be calculated. Simplifying assumptions about the pressure distribution around the structure, allow the flow through the attic with and without the ventilator can be estimated. A complete derivation of the flow through the attic including the simplifying assumptions used is shown in Appendix B.

To predict the net flow through the attic space as a result of the installation of a turbine ventilator, the relative resistance of each flow path and the pressure distribution around the attic had to be estimated. The turbine ventilator installed in the test house has a 305 mm diameter base giving an opening area of approximately 72900 mm^2. The soffit installed on each side of the test house was 2.6 m^2 in area with 3875 perforations per square meter. The perforations were produced by putting the soffit material through a forming process which did not completely remove material but produced a series of louvre-like recesses.

Each recess has an open area of approximately 8 mm by 0.5 mm, producing an net open area of approximately 1.5 percent. The total open area in the soffit on one side of the house was 40300 mm^2 or 55 percent of the area of the turbine ventilator base. Assuming that the soffit and turbine ventilator act like sharp edged holes the relative flow resistance was estimated by considering the free area. Given that the flow resistance is proportional to $1/area^2$, the soffit resistance may be estimated as four times the turbine resistance. Using the analysis shown in Appendix B, the ventilator can be shown to increase exchange rates by approximately 34 percent under the assumed conditions.

Note that, although the open area in the attic through which ventilation air can enter or leave has been approximately doubled the model predicts an increase in exchange rate of 34 percent. Figure 9 indicates the increase in attic ventilation rate expected as a function of the increase in attic exit area. As exit area is added to the attic, the flow through the attic increases as shown in the figure. Since the flow is limited, predominantly by the resistance of the inlet soffit, adding more and more exit area has less and less of an effect on total flow. Eventually, the addition of more exit area will have virtually no effect on the ventilation rate as the flow will be governed entirely by the inlet resistance. At that point the only way to produce increased flow is to reduce the resistance of the attic inlet.

The very limited mathematical analysis undertaken assumed that the pressure distribution was such that flow entered the upwind soffit and exited the downwind soffit and ventilator.

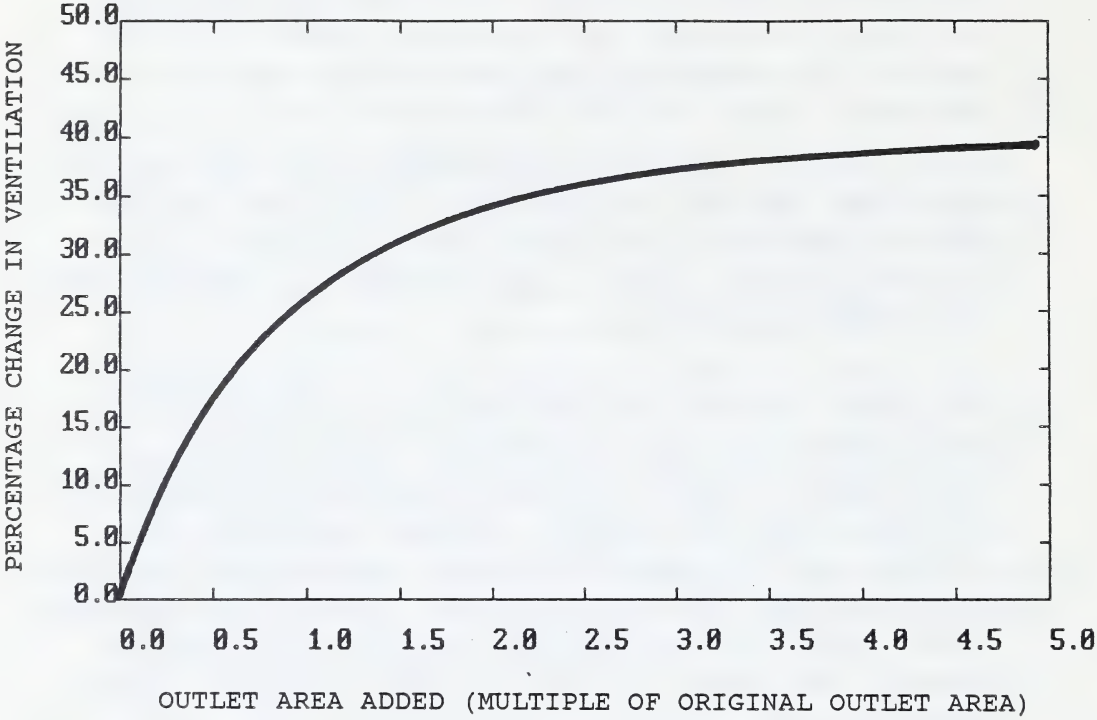


Figure 9. Predicted Change in Attic Ventilation Rates With Opening Size

It should be noted that the pressure distribution around the upper portion of a building and its roof is difficult to estimate as it is a function of wind speed, direction and local sheltering and may never be as assumed. It should also be noted that the positioning of the head of the ventilator, above the peak of the roof, may remove a great deal of direction dependence and as such enhance ventilation in conditions other than those assumed. Based on the above analysis, it should not be assumed that the ventilators are ineffective. What should be realized is that a turbine ventilator should not be expected to greatly enhance ventilation rates. Since the increase in ventilation rate should be moderate (and dependent on initial venting characteristics) it appears in general that the installation of a turbine ventilator would not cause problems of interior condensation to any greater extent than additional venting in the soffit would.

3.2 Prediction from Wind Tunnel Results

In the foregoing analysis, an assumed pressure distribution and flow pattern was used to allow a simple description of a relatively complicated physical system. Neglected in the analysis was any method of dealing with the ventilator as a wind driven centrifugal fan which could conceivably produce a low pressure in the attic space and draw air through the attic at a rate much higher than natural ventilation.

The turbine ventilator tested in the wind tunnel produced flows of 13.8 l/s per m/s of wind speed (50 m^3/hr/m/s). Since the attic of the test house has a volume of approximately 50 m^3 the measured flow through the ventilator would induce an attic exchange rate of one air

change per hour per m/s (1ACH/m/s). This is a rough estimate and would only be accurate if the conditions at the inlet to the ventilator were similar in both the attic and wind tunnel and if the ventilator could produce sufficient static pressure to overcome flow restrictions.

4.0 VENTILATOR INSTALLATION IN A TEST HOUSE

While wind tunnel testing gave an indication of the air speed/flow rate characteristics of the ventilator, it is unlikely that it would accurately reflect the conditions in an actual installation. In most circumstances, the ventilator would be mounted on a sloped roof, near the peak. As a result, pressures inside the attic and outside near the rotating element could be quite different than those used in formulating the simple model. In addition, it would be expected that both the ventilator and the building would see wind speeds influenced by the surrounding terrain and adjacent buildings.

A second ventilator was purchased; a calibrated flow meter was installed, and the calibrated assembly was installed on the roof of a test house at the Alberta Home Heating Research Facility. The mounting location was chosen near the peak to ensure unobstructed air flow from as many directions as possible. A cup type anemometer was mounted on the roof, near the ventilator, to measure local air speed. The rotating element of the ventilator and the anemometer were at the same height above the roof. Figure 10 shows the installation on the roof of House 6 at the facility and the ventilator location relative to the peak of the roof.

4.1 Soffit Modifications

The test house was originally designed with a stepped truss to accommodate insulation up to 0.6 m thick at the intersection of the ceiling and walls as shown in Figure 11. The modifications shown in Figure 11 were made to ensure that the soffit construction and insulation placement reflected residential norms.

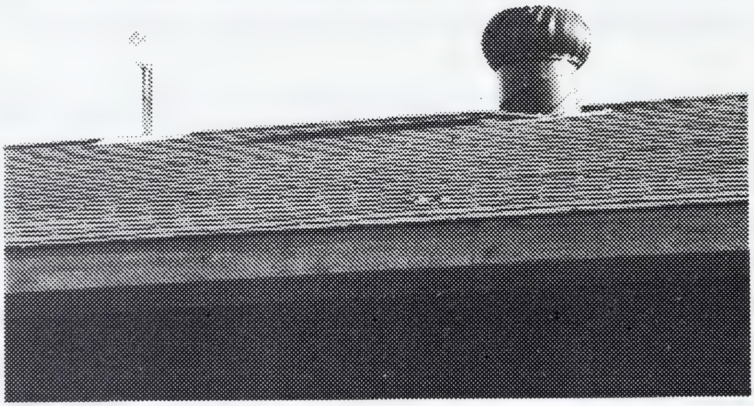


Figure 10. Photograph Showing a Turbine Ventilator Installed on the Roof of a Test House at the Alberta Home Heating Research Facility

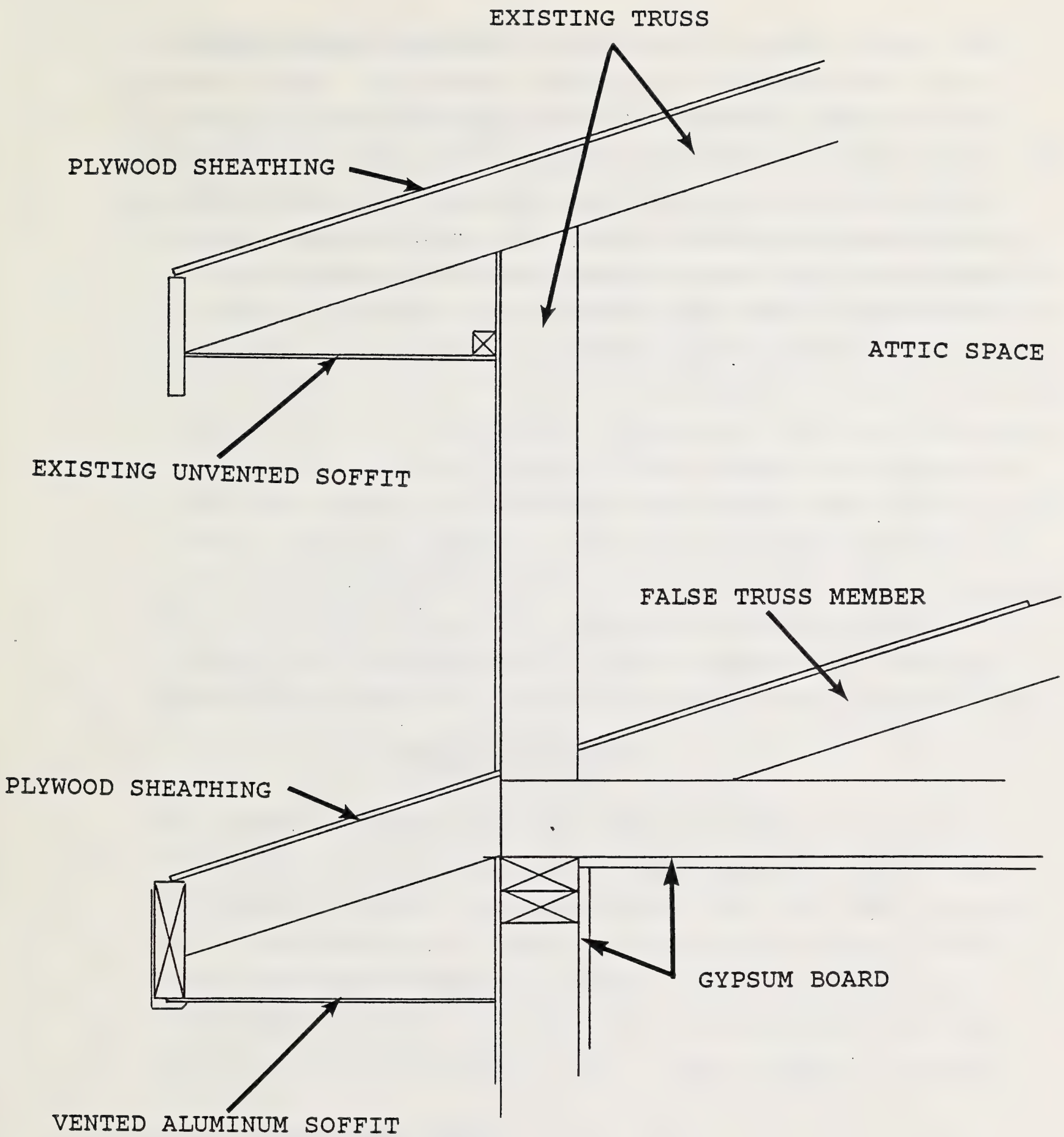


Figure 11. Schematic of the Soffit Modifications Made to the Test House

This meant adding a secondary overhang consisting of a false truss member and plywood sheathing. This construction ensured that the test configuration was similar to residential construction methods in terms of opening size to the attic space, yet still imposed the constraint of a limited amount of insulation over the wall top plate. Because of the stepped truss used in the original construction, the attic volume per unit floor area is about twice that found in a normal bungalow style house.

5.0 EXPERIMENTAL RESULTS

Flow rate through the ventilator, wind speed, ambient temperature and temperatures at various points within the attic were monitored using a computer controlled data acquisition system. The actual attic ventilation rate was measured continuously using a constant concentration tracer gas system. The tracer gas system consists of an infrared gas analyzer, computer controlled data acquisition system, tracer injector and sampling pump. Discrete quantities of a tracer gas, R_{22}, were injected into the attic space at approximately four minute intervals in order to maintain a constant five parts per million (ppm) within the attic space. Multi point sampling from the attic allowed determination of the average gas concentration over the interval. Knowing the concentration of tracer and the quantity of tracer added over any time interval allows the calculation of the ventilation rate,

$$Q = \frac{\text{tracer injected}}{\text{concentration}}$$

In order to determine the effectiveness of the ventilator, attic exchange rates were measured with two different venting configurations: over two week periods with the ventilator free to turn and two week periods with the whole assembly blocked with a plastic cover. It was hoped that the two week back-to-back testing would help eliminate variation due to environmental factors.

5.1 Ventilator Flow Rates

The system was installed in February 1989, but because of problems with a floppy disk controller in the data logger, a large fraction of the data recorded between February and June of that year was lost.

Figure 12 shows the measured flow rate through the turbine ventilator as a function of wind speed measured near the roof. A linear relationship, shown below, was derived from the data using a least squares regression.

$$Q = 33.7U - 10.0$$

As before, the volumetric flow rate, Q, has the units litres per second and the air speed, U, meters per second. Comparison of Figures 6 and 12 shows that flow rates measured in the wind tunnel and in the field differ at all wind speeds. This result indicates that the actual roof conditions were not well simulated in the wind tunnel. Flow rates measured through the ventilator installed on the roof of the test house were approximately 2.5 times higher at any given wind speed than those measured in the wind tunnel. That the flow rates measured in the field would be higher than those measured in the wind tunnel for a given wind speed was expected, given the low pressures produced on the outer roof surface by flow accelerating over the building. A maximum flow rate of approximately 330 l/s (approximately 700 CFM) was observed at a wind speed of 10 m/sec (36 km/hr).

Estimation of the attic ventilation rate may be based on the measured air flow through the ventilator and the volume of the attic. Using a 50 m^3 attic volume the attic ventilation rate would be approximately 2.5 ACH per m/s of wind speed or 2.5 times the estimate made using wind tunnel results.

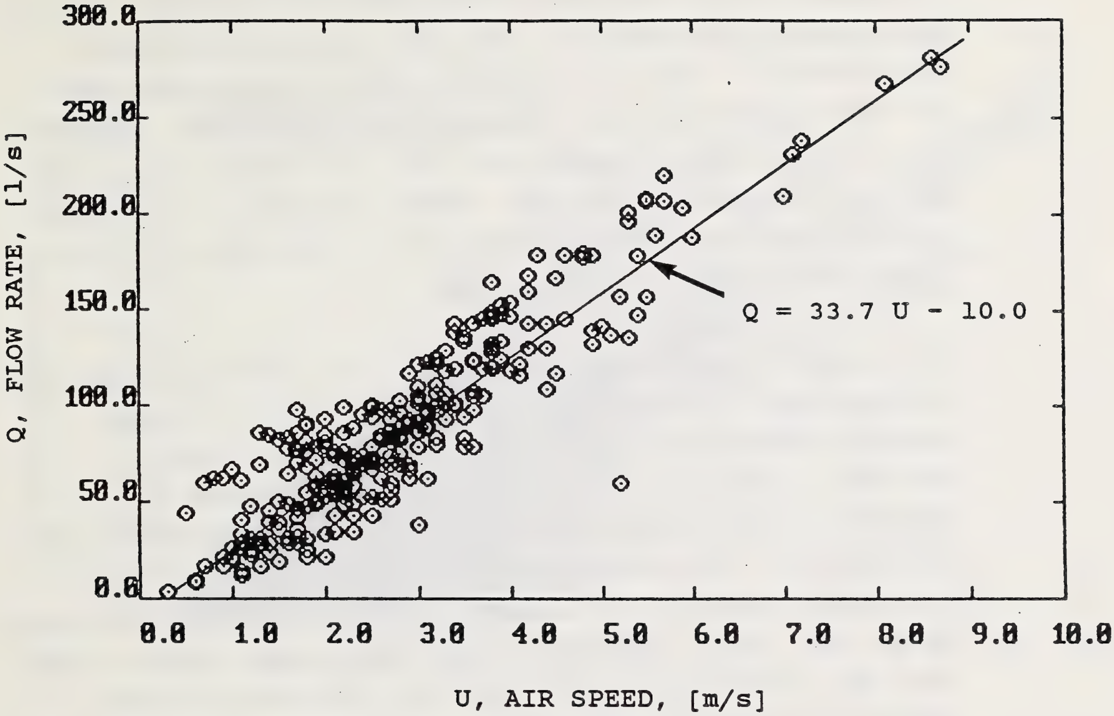


Figure 12. Measured Flow Through a Turbine Ventilator Installed on the Roof of a Test House with Ventilated Soffits

5.2 Attic Ventilation Rates

Attic ventilation rates in air changes per hour (ACH) as determined with the tracer gas system are plotted against wind speed in Figure 13. The data gathered over the period March, 1989 to December, 1989 show periods when the ventilator was both blocked and unblocked. Examination of the figure indicates that, in general, the ventilator appears to provide a small increase in exchange rate. Given the amount of scatter in the data, a quantitative assessment is difficult.

One method of assessing the ventilator effectiveness over long periods of time is to simply calculate average ventilation rates with and without the ventilator. Figures 14 and 15 show frequency distributions of measured attic ventilation rates for each of these cases. Note that in both cases, ventilation rates range from less than one half air change per hour (ACH) to in excess of 20 ACH. Mean exchange rates were found to be 5.3 ACH with the ventilator closed and 6.1 ACH with it open. Frequency distributions were also plotted for wind speed over the same time periods to determine whether a difference in mean wind speed could account for the difference in ventilation rates. As shown in Figures 16 and 17, mean wind speeds were found to be 3.1 m/s for both ventilator open and ventilator blocked periods so that differences in speed alone could not account for the result seen. Based on the average measured exchange rates over the test interval, the turbine ventilator appears to have enhanced attic ventilation rates by 15 percent.

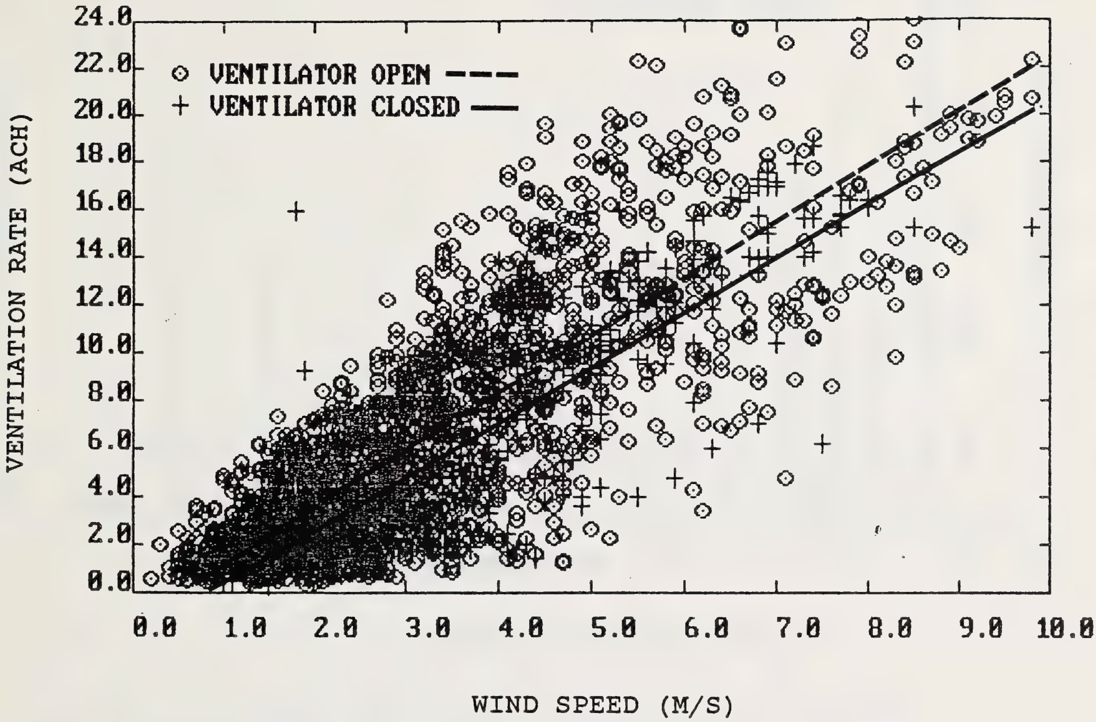


FIGURE 13: Measured Attic Ventilation Rates for Winds From All Directions

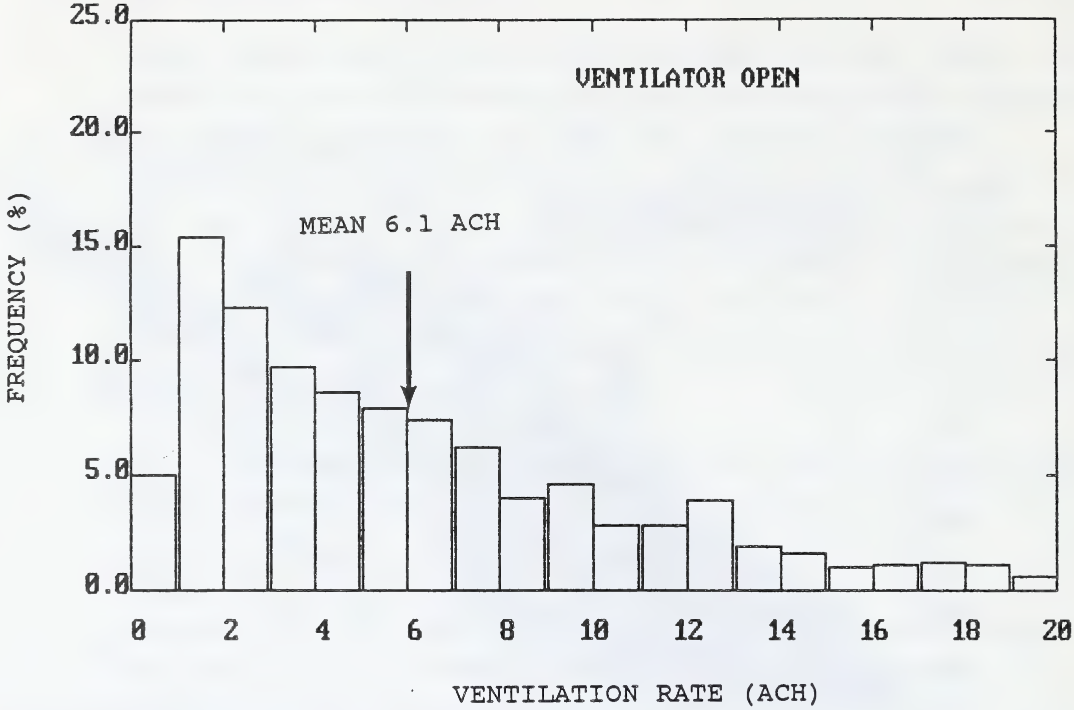


FIGURE 14: Frequency Distribution of Measured Attic Ventilation Rates, Turbine Ventilator Open

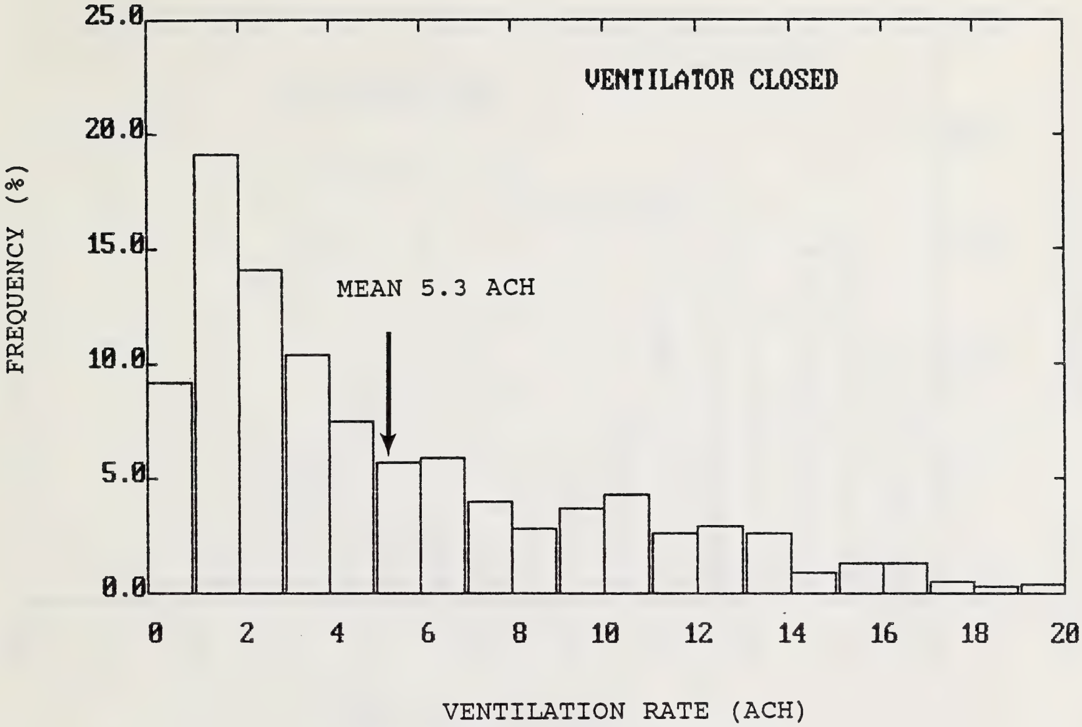


FIGURE 15: Frequency Distribution of Measured Attic Ventilation Rates, Ventilator Closed

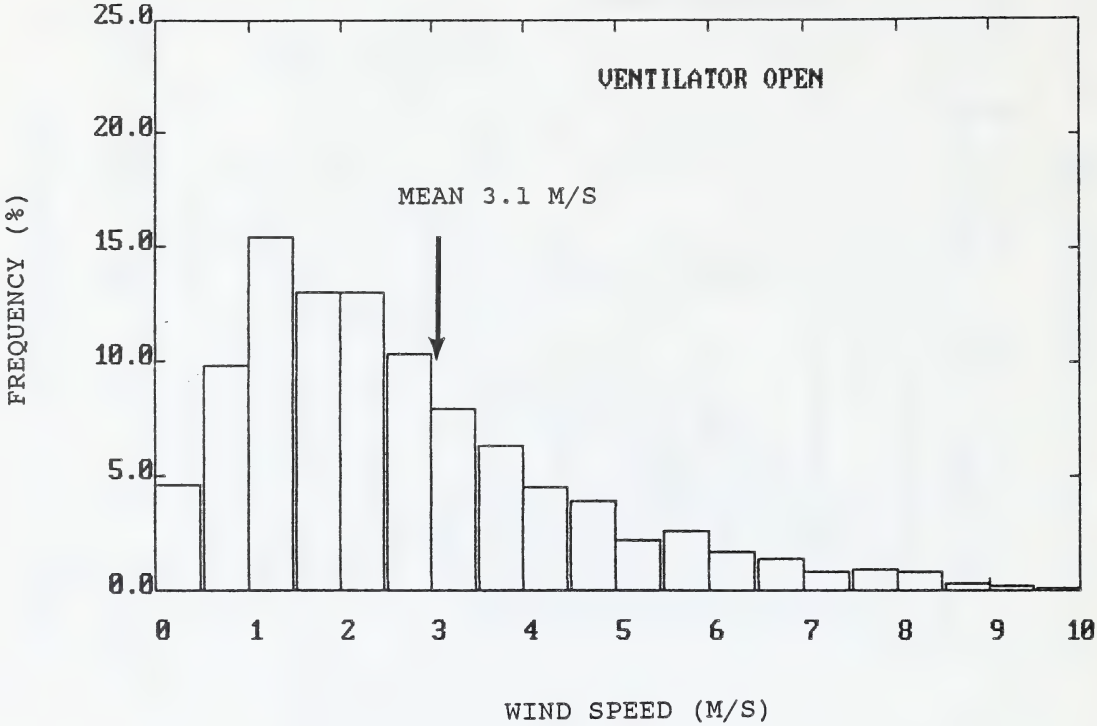


FIGURE 16: Frequency Distribution of Wind Speed During Ventilator Open Periods

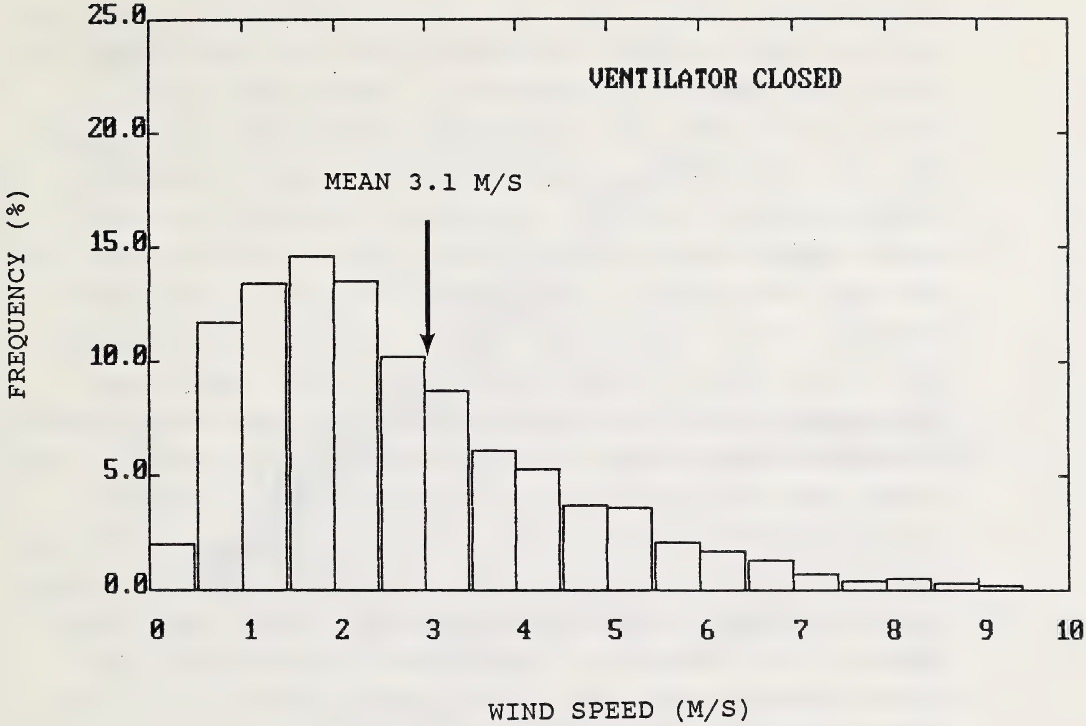


FIGURE 17: Frequency Distribution of Wind Speed During Ventilator Closed Periods

The test houses at the Alberta Home Heating Research Facility are situated in an east-west row so that shielding is far greater for east or west winds than for north or south winds. Separating the available data by direction, Figures 18 through 21, shows that attic ventilation rates are a function of not only wind speed but also direction. Figures 18 and 19 show exchange rates measured under the influence of north and south winds respectively while Figures 20 and 21 show data for east and west winds. In general, it can be seen that exchange rates are greater at all wind speeds when the wind direction is either north or south. Under the influence of north or south winds, the ventilator appears to provide enhancement of approximately 10 percent. The house used for testing was constructed with vented aluminum soffit on the north and south with gable soffits made of unvented plywood. It is surmised that blocking or unblocking of the ventilator under these conditions causes little change in ventilation rate because the major resistance to flow is the small open area in the vented soffits. This means that the amount of air exchange within the attic space is governed by the resistance to air flow produced by the soffit. During periods when winds are from the north or south, flow through the attic appears to be in through the upwind soffit and out through the downwind soffit and ventilator. When winds are from the east or west, one would expect to see reduced exchange rates due to the shelter provided by adjacent buildings. The ventilator appears to be much more effective when winds are from either east or west, providing increased ventilation of the order of 25 to 50 percent. During periods of east or west winds, it is difficult to estimate generalized flow patterns through the attic.

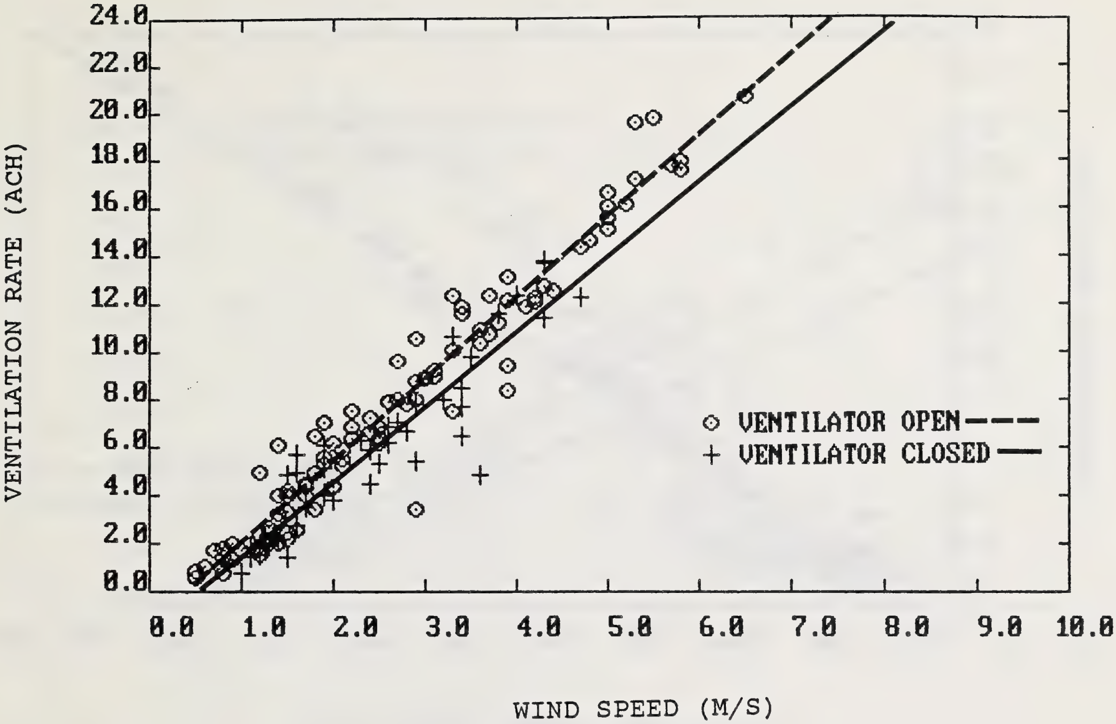


FIGURE 18: Measured Attic Ventilation Rates for North Winds with the Ventilator Both Open and Closed

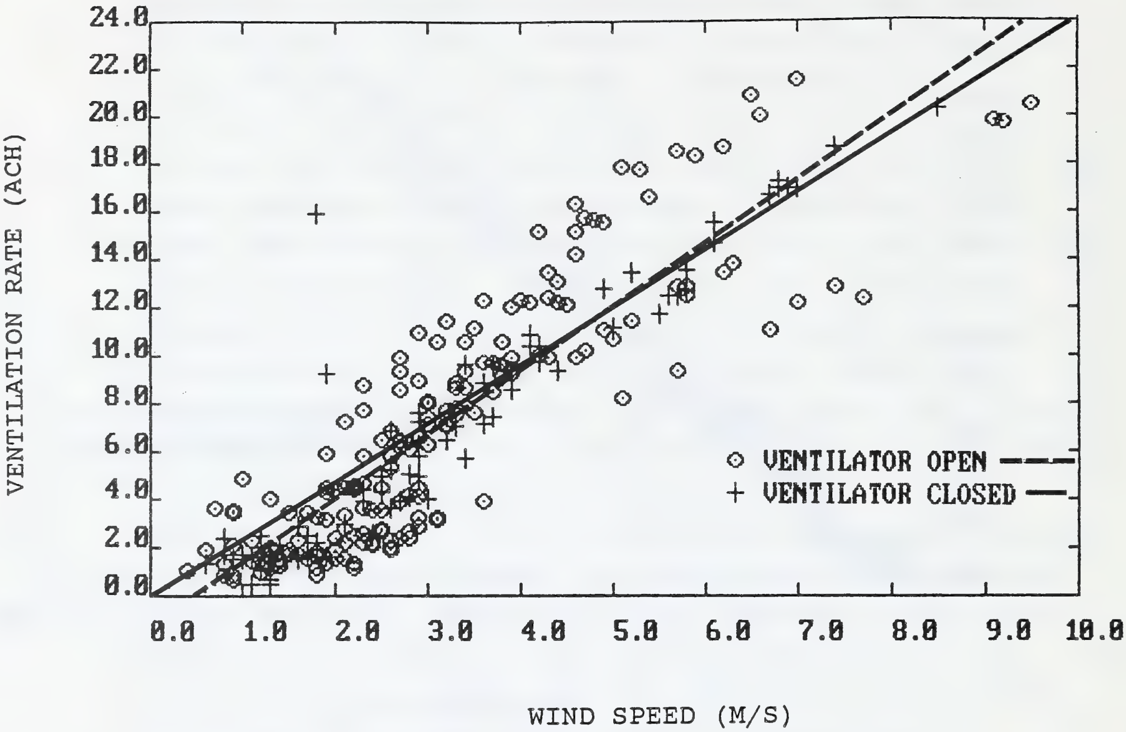


FIGURE 19: Measured Attic Ventilation Rates for South Winds with the Ventilator Both Open and Closed

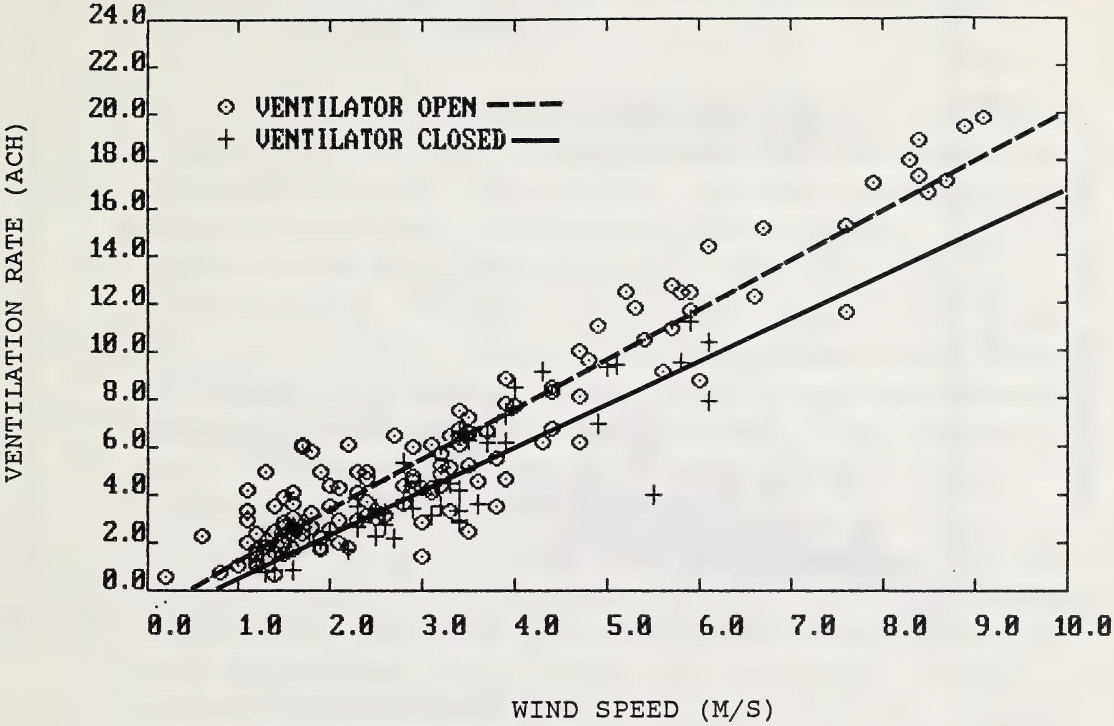


FIGURE 20: Measured Attic Ventilation Rates for East Winds with the Ventilator Both Open and Closed

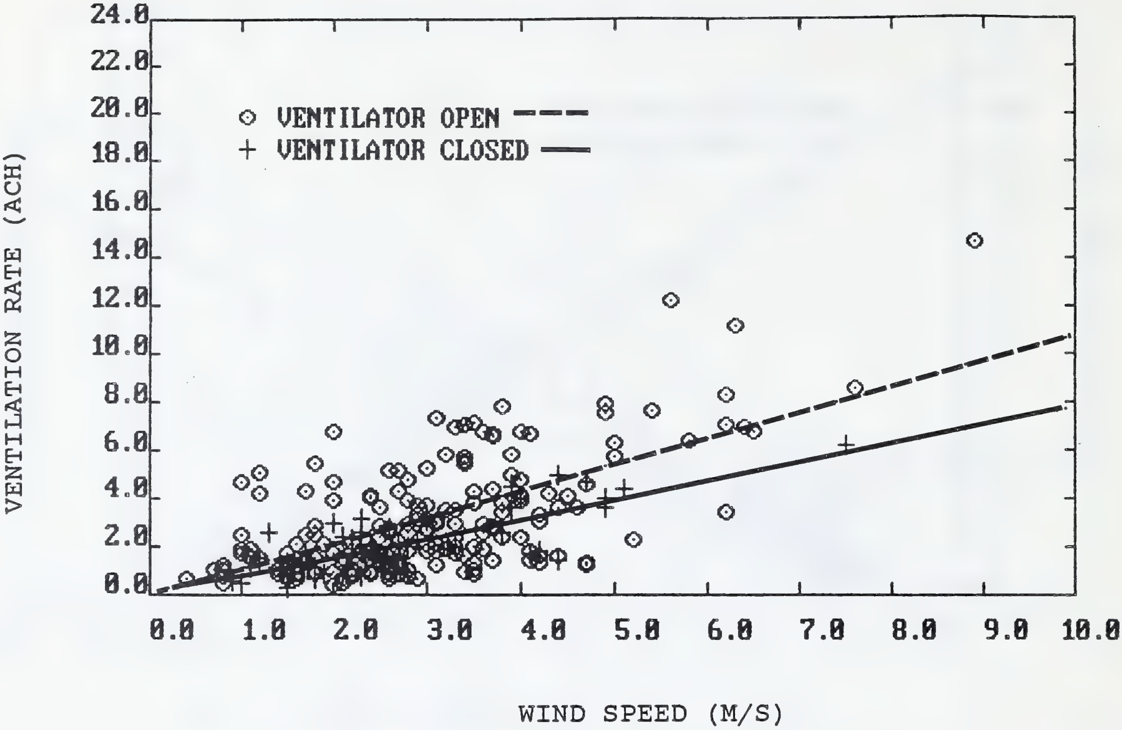


FIGURE 21: Measured Attic Ventilation Rates for West Winds with the Ventilator Both Open and Closed

It is likely that the soffit vents still provide the bulk of the resistance to flow, but that generally the flow will be in through both north and south soffits and out through the ventilator.

In order to observe the effect of wind direction on ventilator effectiveness, the available data was binned in 30 degree direction increments. The data in each bin was used to calculate a linear relationship between ventilation rate and wind speed for both ventilator open and closed periods. Figure 22 shows the slope of each best fit line, plotted against the corresponding predominant wind direction. (Directions measured in degrees clockwise from North) No data were collected for winds between 210 and 240 degrees. The variation in the slope between direction bins can be interpreted as being due to differences in the physical construction of the attic as well as the variation in wind sheltering from surrounding structures. The ratio of the slope of the best fit line with the turbine open to that with the turbine closed gives an indication of the degree of ventilation enhancement afforded by the attic ventilator in each direction bin.

$$\text{enhancement} = \frac{\text{slope of best fit line with ventilator open}}{\text{slope of best fit line with ventilator closed}} - 1$$

Figure 23 shows the percentage change in attic ventilation rate over a wind angle range of 0 to 360 degrees with 0 and 360 both indicating north. Note that the maximum changes occur for east and west wind directions - the directions with the greatest amount of upwind shelter.

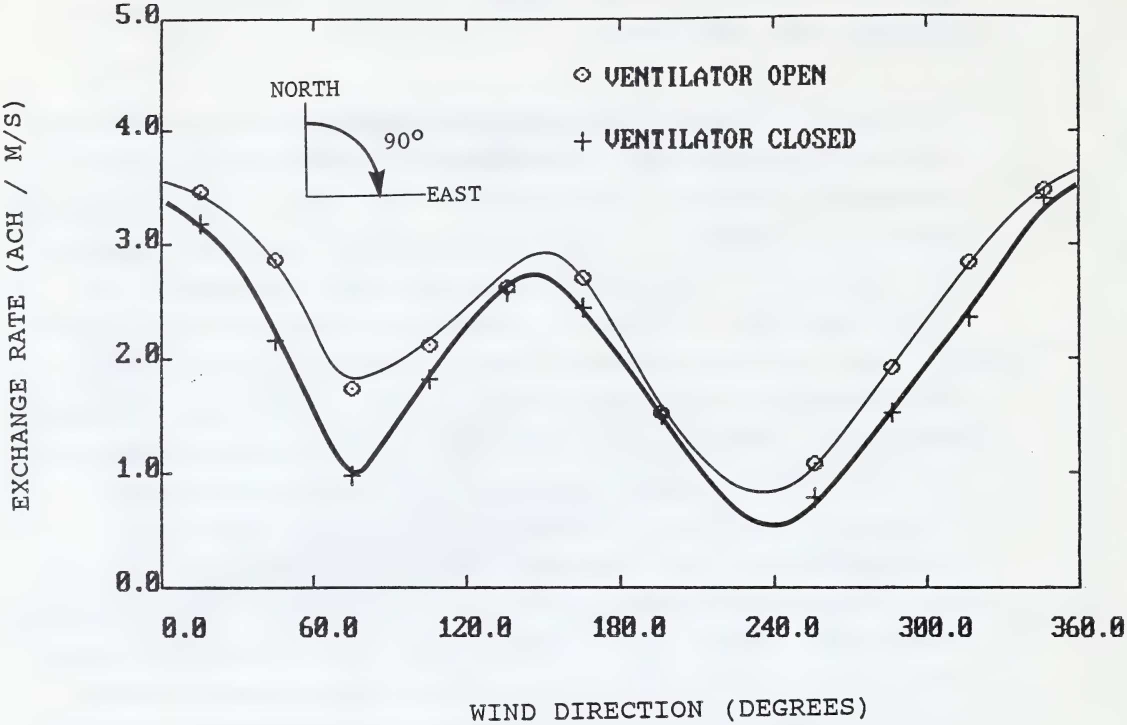


FIGURE 22: Variation in the Attic Ventilation Rate of a Partially Sheltered Test House with Wind Direction

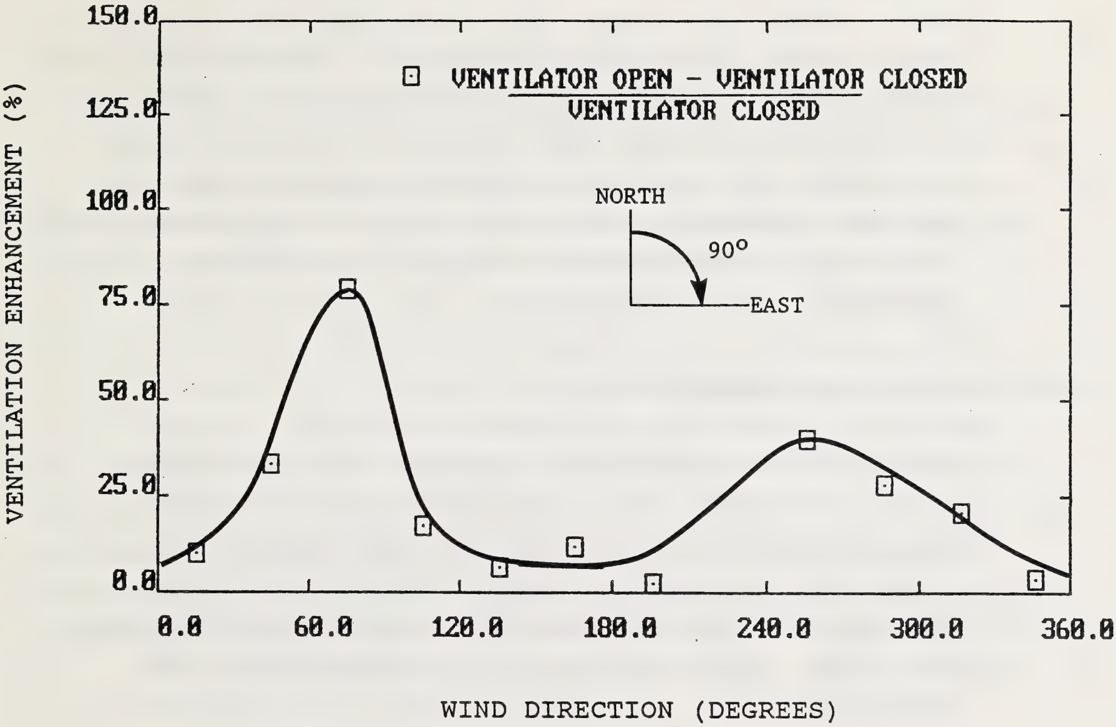


FIGURE 23: Enhancement in Attic Ventilation Rate Due to a Turbine Attic Ventilator as a Function of Wind Direction for a Partially Sheltered Test House

This is an expected result as the rotating element of the ventilator is above the roof peak and as such, would see more uniform wind speeds from all directions than the soffit vents. The smallest amount of enhancement occurs, as it should, when the wind is blowing from directions which produce the greatest exchange rates. In those situations, the upwind and downwind soffits see the greatest difference in pressure so the cross ventilation is already great and the ventilator contributes a lower percentage of the total flow.

5.3 Attic Air Temperatures

The primary reason for the purchase and installation of a turbine ventilator by a consumer has been cited as being the removal of warm air from the attic space during the summer months. Adequate venting of an attic space has two benefits: it can make the living space more comfortable and it can reduce the amount of energy used in air conditioning.

Attic air temperatures were measured throughout the duration of the study - during periods when the ventilator was open and when it was blocked. Evaluation of the results is, however, quite difficult as attic temperature is a function of not only ventilation rate but also ambient temperature and the amount of solar radiation falling on the roof surface. In addition, the magnitude of the reduction of energy transfer to the living space is dependent not only on the air temperature in the attic space and the insulation level but also on what fraction of the total heat transfer occurs through radiation from the underside of the roof sheathing to the top surface of the insulation. If the radiation component is a large fraction of the total, the lowering of the

attic air temperature through ventilation will not reduce the heat transferred to the living space by as much as one might imagine.

Attic temperature data for the spring and summer months were sorted into two groups - with and without the ventilator operating. The groups of data were binned in 1°C increments of attic air temperature minus ambient air temperature and plotted in histogram form as shown in Figures 24 and 25. With the ventilator operating, Figure 24, attic temperatures ranged from 4 degrees below ambient to 23 degrees above during the April to September period. The mean temperature difference during the period was 5.6 degrees, indicating that on average the attic was 5.6°C warmer than the ambient air. Figure 25, representing the period when the ventilator was not operating, shows a nearly identical distribution with a slightly higher maximum temperature difference of 25°C. The mean temperature difference during the ventilator closed period was 6 degrees.

Comparison of the average temperature differences obtained with the ventilator operating and those with the ventilator blocked gives an indication of the effectiveness of the ventilator in reducing attic temperature and heat transferred to the living space. The data show a change in the attic-ambient temperature difference of 0.4°C over the summer period. Whether this change can be attributed to the attic ventilator or simply small differences in wind speed, wind direction and solar radiation is not known. Given the insulation levels commonly found in residential attics, it is unlikely that the amount of energy transferred to the living space was reduced appreciably.

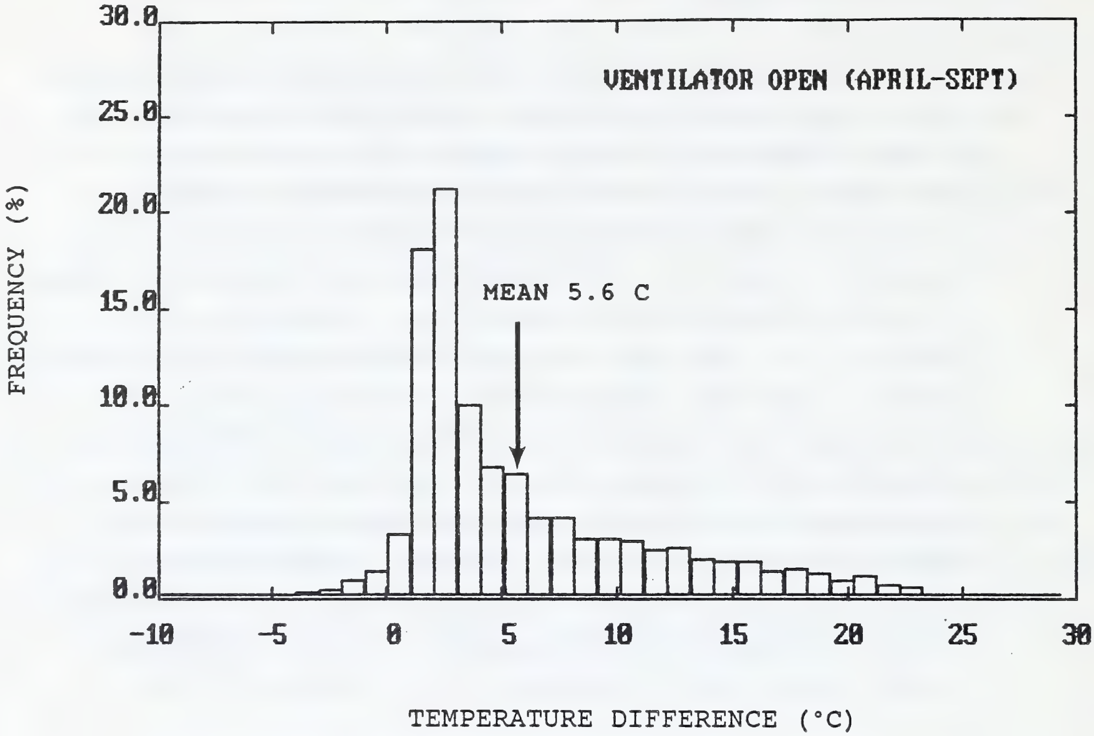


FIGURE 24: Frequency Distribution of Attic - Ambient Temperature Differences During the Summer Months with the Ventilator Operating

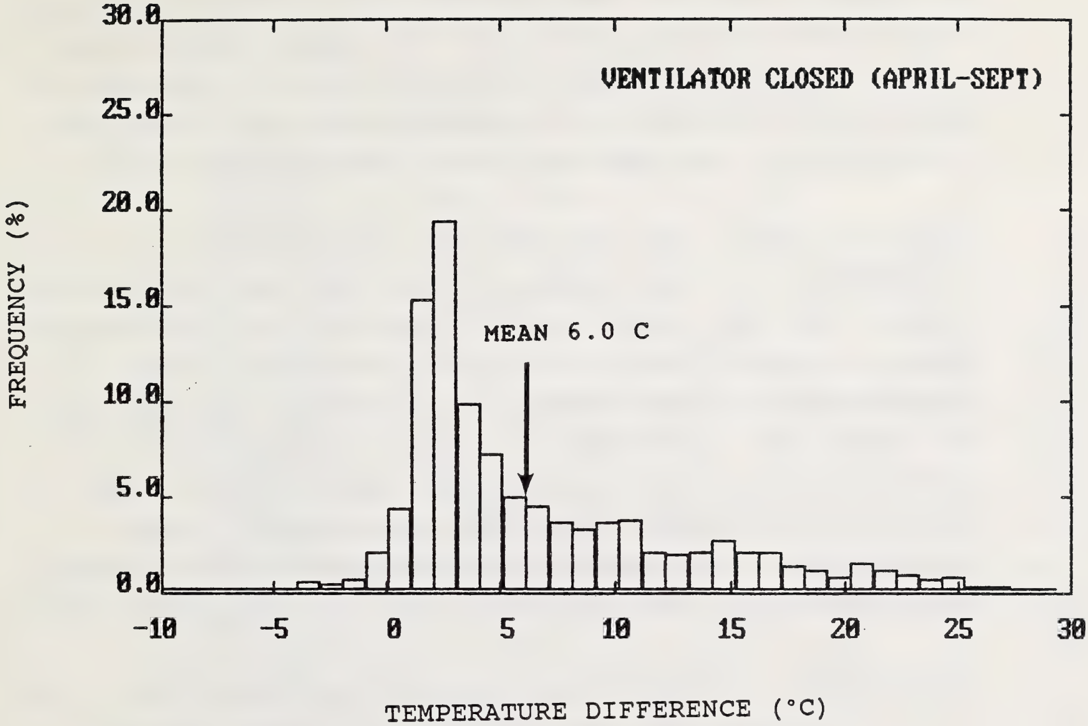


FIGURE 25: Frequency Distribution of Attic - Ambient Temperature Differences During the Summer Months with the Ventilator Blocked

5.4 Attic Insulation Temperatures

In order to evaluate the potential for moisture condensation on the interior surface of the gypsum board during winter conditions, temperature measurements were made on the interior surface of the gypsum board and within the insulation on the north and south sides of the attic.

Figure 26 shows the locations of thermocouples in relation to the wall framing members and the wall/ceiling joint. Note that over the wall, there is only sufficient space to install RSI 2.11 (R 10) insulation. Seven thermocouples placed within the insulation as shown give an indication of whether air is drawn through the insulation at a rate which would impair effectiveness. The interior surface temperature measurement allows estimation of the ambient conditions required to produce condensation on the interior surface of the gypsum board.

Measurements were taken in February and March, 1989. In order to produce the most extreme conditions possible, sections of soffit in the immediate vicinity of the temperature probes were removed. This was done to maximize the volume of air drawn into the attic at the measurement locations. During the test period, the interior of the house was humidified on a continuous basis, producing relative humidities of approximately 40 percent at 21°C. For condensation to occur on the interior surfaces of the walls, the interior surface temperature would have to fall below the dew point, about 7°C. Figure 27 shows temperatures measured at various locations for a day in March with an ambient temperature of -3°C, winds from the south at 5.5 m/s (20 km/hr) and the ventilator operating.

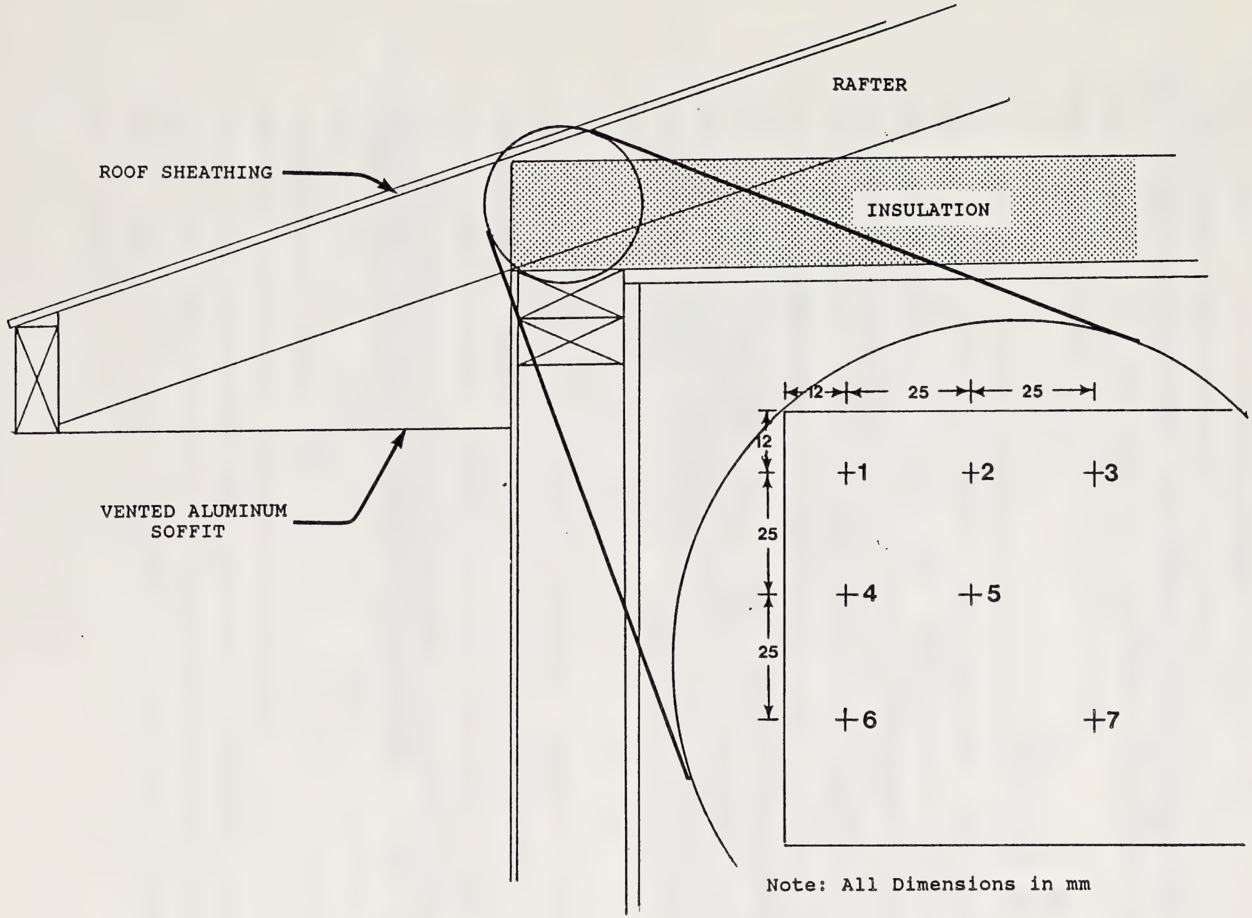


FIGURE 26: Schematic Showing the Placement of Thermocouples Within the Attic Insulation

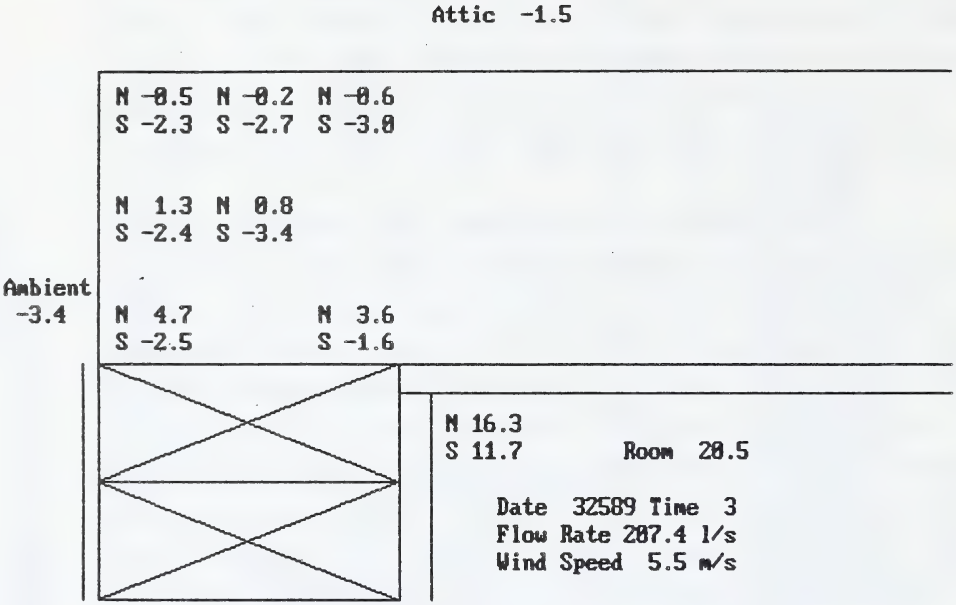


FIGURE 27: Measured Temperatures in the Attic Insulation Indicating a Net Flow From South to North

Under these conditions, the temperatures measured on interior drywall surface near the intersection of the wall and ceiling were 16°C on the north side and 11°C on the south. It is evident from the measurements that ambient air entered the attic through the south soffits and exited through the ventilator and the north soffits. The interior surface did not reach the dew point but ambient conditions were relatively mild.

To assess the potential for condensation on the interior surface of the drywall, data from November and December, 1989 were examined. Figure 28 shows ambient temperatures over the two month period binned in 1 degree intervals. While it cannot be said that the period studied covers a full range of typical winter conditions, ambient temperatures ranged from -29°C to +18°C. During the entire period, the ventilator was operated to provide the most severe conditions possible (highest flow rates) in the attic insulation.

Figures 29 and 30 show hourly average interior surface temperatures measured at the location indicated in Figure 26 on the north and south sides of the house respectively. As previously noted, condensation should not occur until such time as the surface temperature drops below the dew point. Figure 29, north interior surface temperature, shows that over the November - December period, the surface temperature dropped below 7°C for 26 hours or 2 percent of the interval. Surface temperatures lower than the dew point on the south side of the test house were even less frequent, at less than 1 percent of the interval.

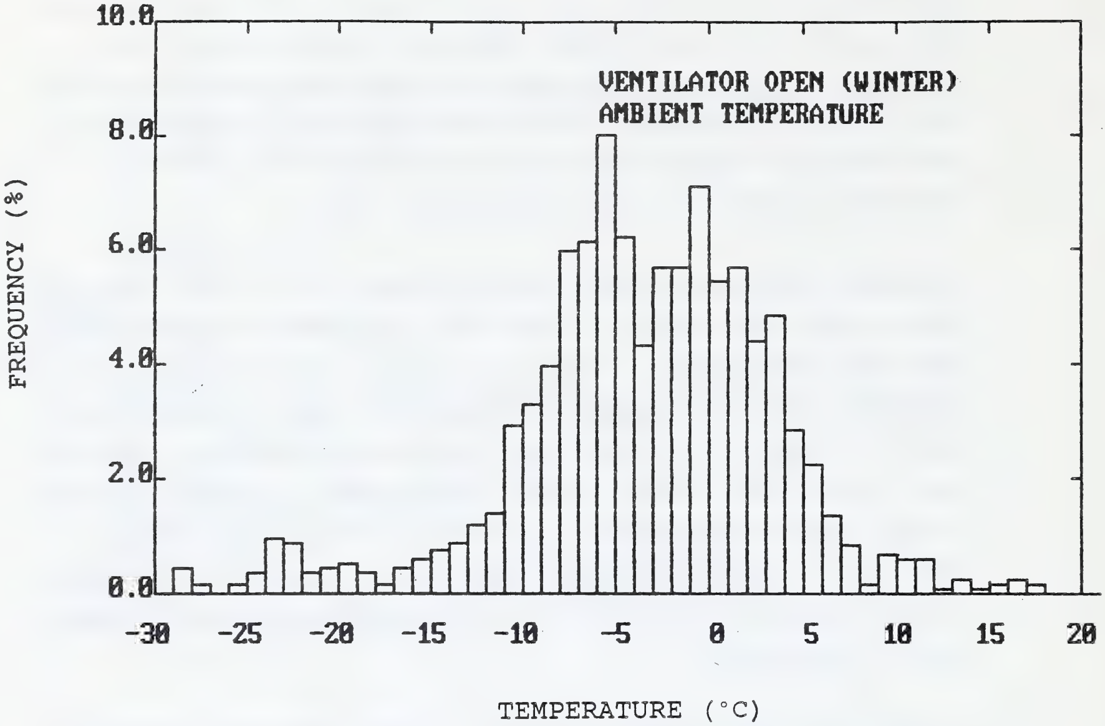


Figure 28: Frequency Distrubution of Ambient Air Temperature at the Test House Location November and December, 1989

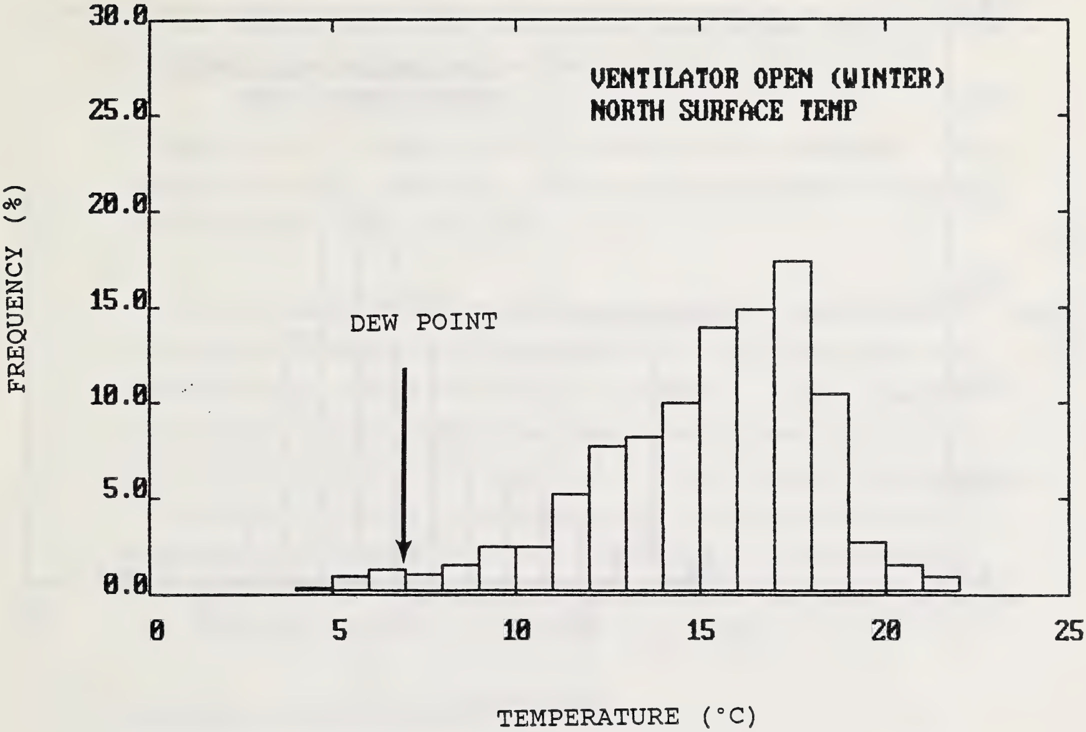


FIGURE 29: Frequency Distribution of Hourly Average Surface Temperatures During Winter, North Ceiling Location

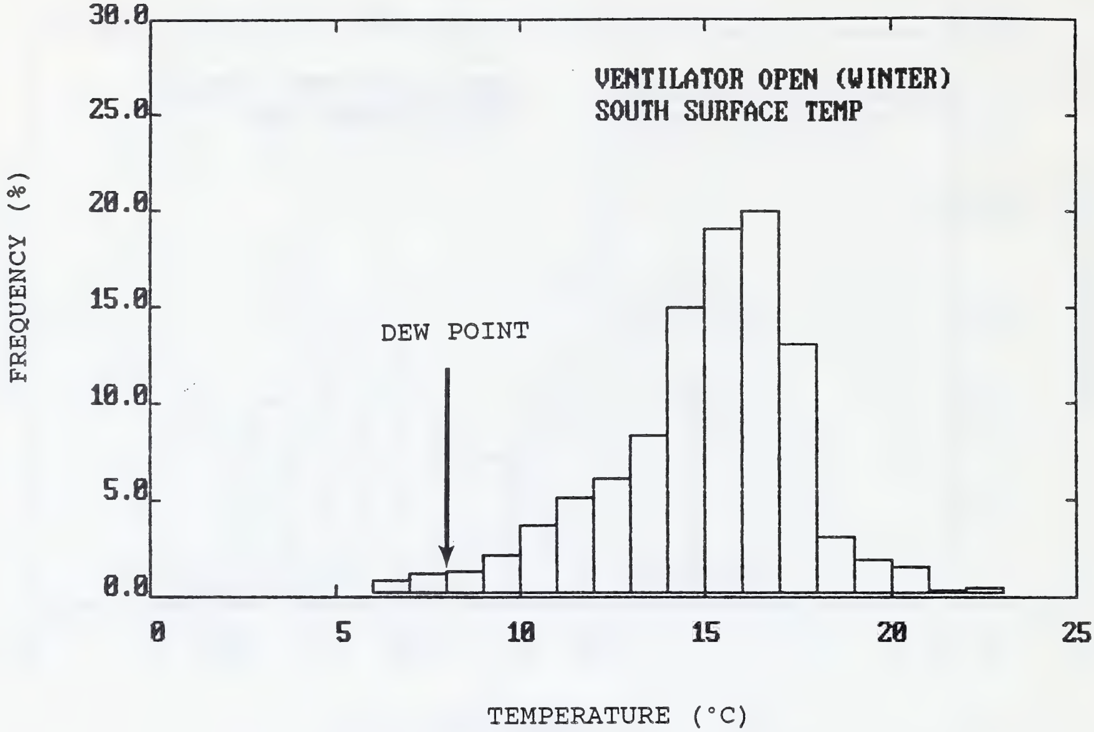


FIGURE 30: Frequency Distribution of Hourly Average Surface Temperatures During Winter, South Ceiling Location

The lower frequency seen on the south side of the structure is probably due to the south wall of the house being warmed by solar radiation and transferring some of that energy to the air entering the south soffit.

Although the potential for condensation existed for a portion of the interval, there was no evidence that condensation had occurred.

It was evident from surface temperature measurements that the effectiveness of the insulation in reducing heat transfer was impaired by air movement. This result should not be misconstrued as being a result of ventilator operation. As long as a path through the insulation into the attic exists, some fraction of the air entering the attic will pass through the insulation. Whether or not the ventilator accentuated this problem was not conclusively shown by the study.

5.5 Measured Rates of Heat Transfer

Interior surface temperature measurements showed limited potential for interior condensation due to air flow through the ceiling insulation. The flow of air through the insulation can be greatly impeded by the installation of impermeable barriers such as the insulation stops, used with loose fill insulation to keep it out of the space above the soffits. Barriers to air movement through the insulation should have the effect of reducing rates of heat transfer while increasing interior surface temperature and further decreasing the potential for condensation.

In order to evaluate the effectiveness of insulation stops, heat flow transducers were placed on the ceiling to measure the rates of heat transfer at various ventilation rates. Figure 31 shows the locations of the transducers relative to the wall-ceiling intersection.

Rates of heat transfer were measured for several weeks before and after cardboard inserts, similar to insulation stops, were installed. The inserts were placed as indicated in Figure 31 so that an unobstructed path to the attic remained while flow through the insulation was stopped. The measured rates of heat transfer along with room-attic temperature differential were used to calculate an effective thermal resistance on an hourly basis. Figure 32 shows the effective thermal resistance measured at two locations on the south side of the test house over one week in January, 1990, while Figure 33 shows wind speed over the same interval. The cardboard air stops were put in place at approximately hour 82. There was an immediate increase in the effective thermal resistance at both locations with the largest increase shown at the location furthest from the wall. The large decreases in resistance between hours 36-50 and hours 72-80 show the strong dependence on wind direction. During both periods wind was from the south, resulting in flow in through the south soffits and out through the north soffits and ventilator. After the installation of the barriers, the dependence on wind direction and on wind speed was largely removed indicating that the stops were effective in limiting air flow through the insulation.

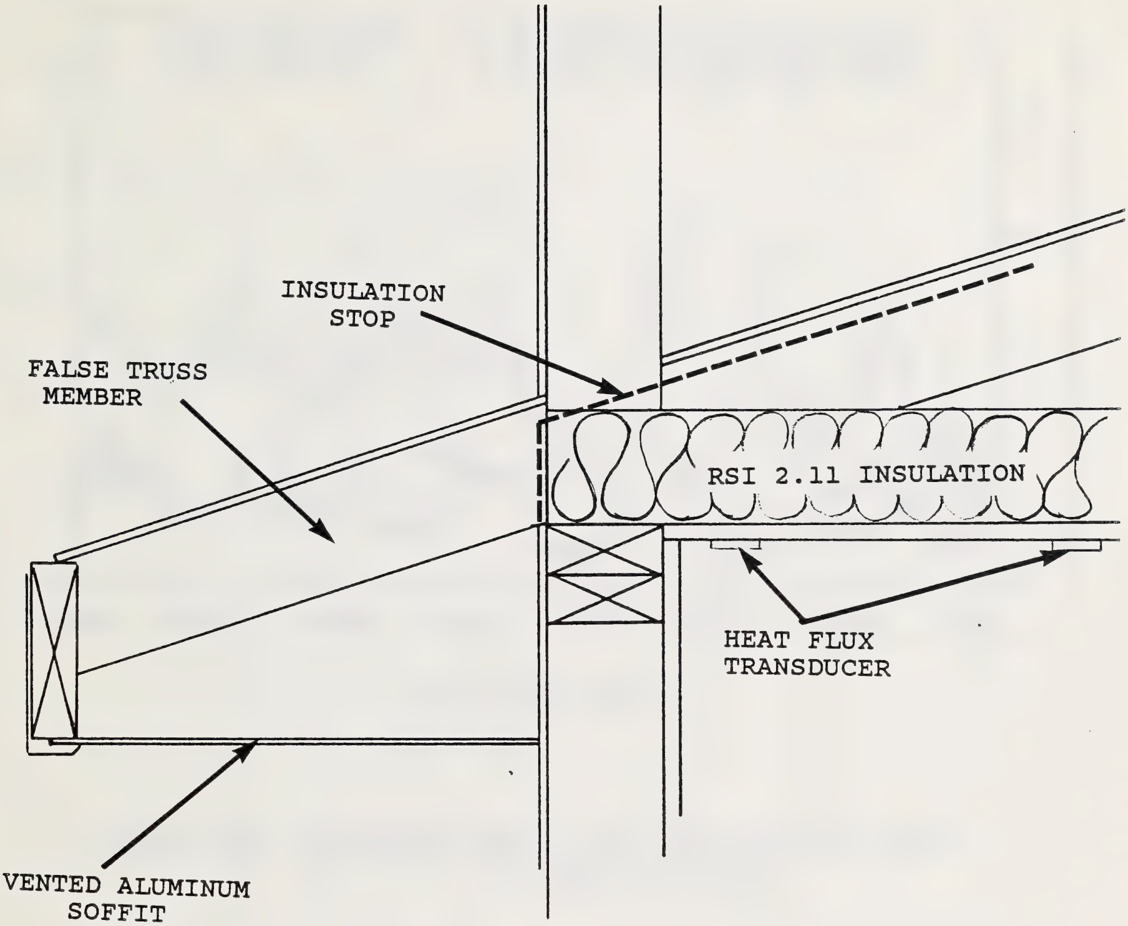


Figure 31 Location of Heat Flux Transducers Installed on the Ceiling of the Test House

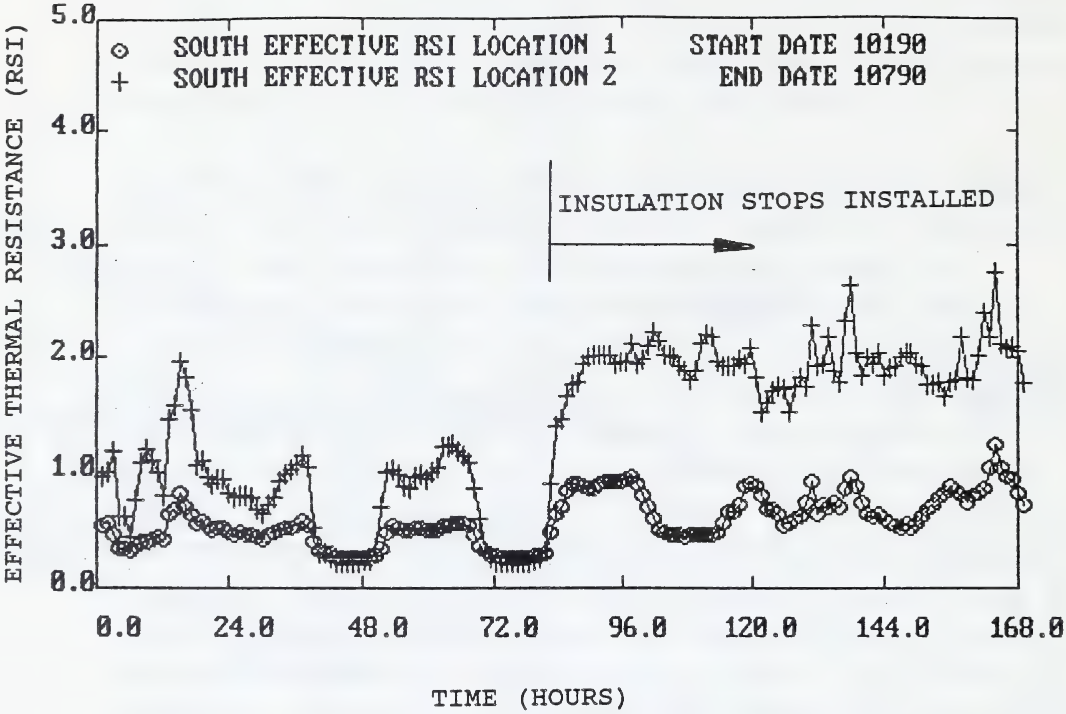


Figure 32 Measured Heat Flux Through the Ceiling of the Test House With and Without Barriers to Limit Air Flow

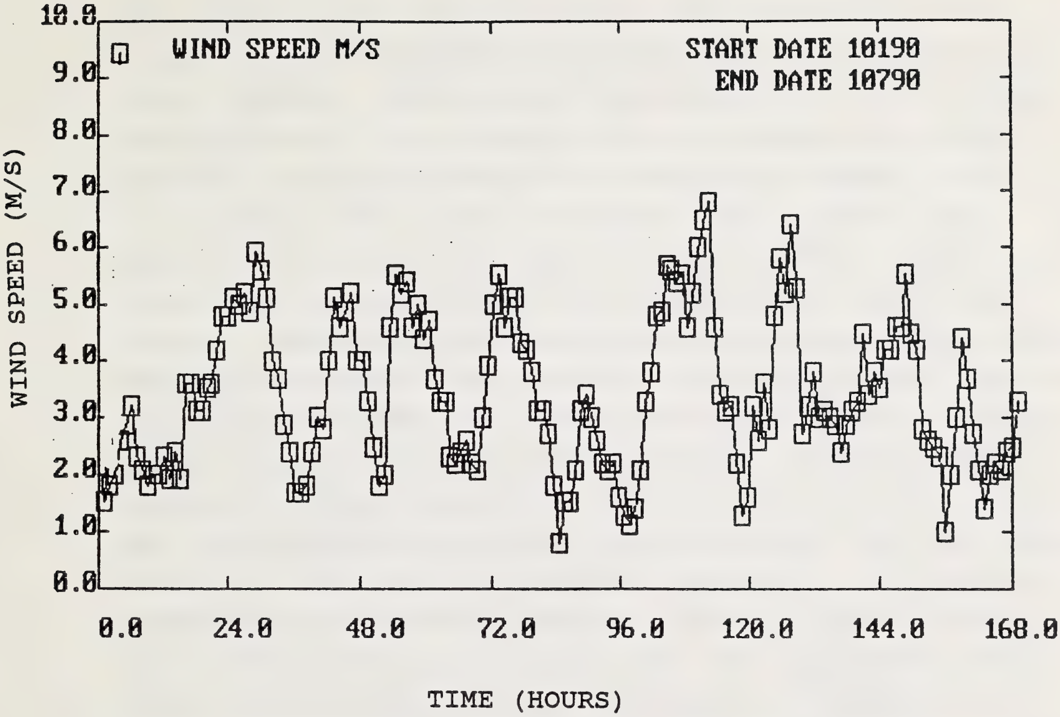


Figure 33 Wind Speed Measured on the Roof of the Test House, January 1-7, 1990

6.0 MEASURED AND PREDICTED PERFORMANCE

The objective of the study was to evaluate the performance of attic turbine ventilators through laboratory and field studies. Wind tunnel measurements of flow through the ventilator as a function of wind speed, if applied directly to the estimation of ventilation rates in an attic would lead to the conclusion that a ventilator should be extremely helpful in reducing attic temperatures and heat transfer to the living space during the summer. Similarly, estimating the attic ventilation rate based on measured flow through a ventilator would lead to the conclusion that the ventilator would provide a great deal of enhancement. It is only when a measured attic exchange rate is compared to flow through the ventilator and to exchange rate without the ventilator that the true effect of the ventilator becomes apparent. The greatest enhancement is provided when the wind is blowing from a sheltered direction. In this case, the measured results shown earlier indicate that increases in exchange rate can be as high as 50 percent. For most other directions, the enhancement is much less and depends on the physical construction of the attic and initial venting provisions.

In order to properly assess the effect of the addition of a turbine or any other type of ventilator, the concept of optimal ventilation rate must be addressed. Prior to this study, there was very little information available on the ventilation characteristics of attics, nor was there any good estimate of the range of ventilation rates one might encounter in a residential attic. Measured attic ventilation rates (without a turbine ventilator) over the course of the study varied between 1 and 20 air

changes per hour with an average of more than 5 air changes per hour. Given this level of exchange rate in an attic which simply has soffit vents, the need for enhancement becomes questionable.

7.0 CONCLUSIONS

The ventilation rate of an attic is dependent on a number of parameters such as the type of soffit, the free area of the soffit, wind speed and local sheltering. There is a large degree of uncertainty associated with estimated rates as derived through laboratory experimentation.

Based on wind tunnel measurements of air flow through the turbine, one would expect the ventilation rate in an attic the size of the field test house to be greatly enhanced. Experimental results indicate that the ventilation rate within the test house attic would be approximately one air change per hour per m/s of wind speed. This figure is based on flow through the turbine and the volume of the test house attic.

Using measurements obtained in the field for flow through the ventilator leads to an estimate of attic ventilation rate of about 2.5 times the wind tunnel estimate or 2.5 ACH/m/s. Again, this figure is based only on measured flow through the ventilator and attic volume.

Using the simple model derived for attic ventilation, an estimate of the change in ventilation rate due to the installation of a turbine ventilator was made. Given the assumptions that were used in deriving the model and recognizing that the potential for increased ventilation is a function of the initial ventilation rate, a prediction of 20 - 30 percent increase in ventilation is reasonable.

Attic ventilation rates were found to vary from less than 1 ACH to more than 20 ACH, with an average of 5.3 ACH when only soffit vents were used, and 6.1 ACH when the

turbine ventilator was used in addition to soffits. Enhancement provided by the turbine ventilator was found to be wind direction dependent and ranged from less than 5 percent to more than 50 percent. Based on average measured exchange rates, the turbine ventilator provided an actual increase of 15 percent in attic ventilation rate over a one year period.

It was found that flow into the attic through soffit vents was such that the effectiveness of insulation placed over the wall top plate was reduced, and that insulation effectiveness over the top plate could be largely restored by the use of insulation stops. The potential for interior condensation on the ceiling near the wall-ceiling intersection increased with the severity of ambient conditions, but it was not shown conclusively that the installation of a turbine ventilator would increase the risk appreciably.

Experimental work was undertaken using only one turbine attic ventilator on the roof of the test house. Multiple turbine attic ventilators, as are used in some installations, should provide a marginal enhancement over that afforded by a single ventilator. Again, unless one or more of the ventilators acted as inlets rather than outlets, the overall ventilation rate would be governed by the resistance of the inlet soffit material.

APPENDIX A

Alberta Home Heating Research Facility Site Plan

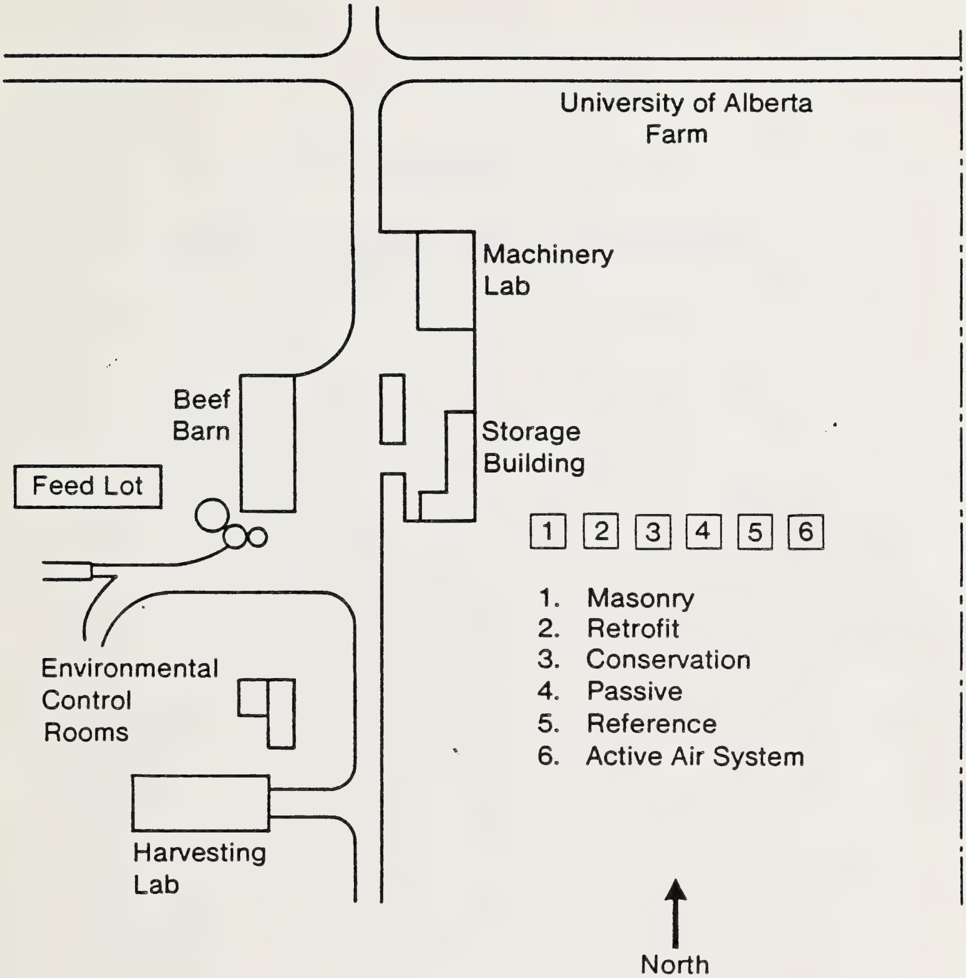


Figure A1 Site Plan of the Alberta Home Heating Research Facility

APPENDIX B

Simplified Attic Ventilation Model

APPENDIX B - Simplified Attic Model

The derivation of a simplified model of attic ventilation and can provide a better understanding of the potential a turbine ventilator may have for enhancing attic ventilation. Figure 7 in the main body of the report shows a generic attic in a house with a gable roof and vented soffits. Assuming, for simplicity, that the wind is from a direction perpendicular to the line of the roof peak, one can imagine a general flow path through the attic. Flow entering the upwind soffit and exiting through the downwind soffit would be regulated by the pressure distribution surrounding the attic and the flow path resistance. The physical system may be described by an electrical analogy in which voltage drop would represent the upwind - downwind pressure differential, resistance would represent the characteristic of the soffit to impede flow and current would represent air flow. The electrical analogy for the attic with and without a turbine ventilator is shown in Figure 8. As shown, the electrical analogy for the attic with no ventilator would simply be two resistances in series. The analysis is slightly more complicated since flow through sharp edged holes, such as the perforations in soffit material, is not directly proportional to pressure differential but to the square root as indicated below:

$$Q = C\sqrt{\Delta P} \qquad (1)$$

The electrical analogy may be carried further if equation (1) is rearranged in terms of head loss as shown in (2).

$$\Delta P = (Q/C)^2 \qquad (2)$$

Equation (2) represents the pressure or head loss across any flow path resistance that behaves like a sharp edged hole. Writing equation (2) in a form similar to Ohms Law and setting $1/C^2$ equal to K results in equation (3).

$$\Delta P = KQ^2 \tag{3}$$

Thus, when the flow is in the upwind soffit and out the downwind soffit, the electrical analogy consists of two resistances in series with the total flow governed by the overall pressure differential and the sum of the two resistances. When the ventilator is present, the electrical analogy becomes more complicated as there are two flow resistances in parallel, the ventilator and the downwind soffit, and these two are in series with the resistance due to the upwind soffit. The electrical analogy for this configuration is also shown in Figure 8. The system may be described in terms of head loss (ΔP) across each flow resistance. Equations (4) and (5) describe the head loss across the soffit and attic ventilator respectively.

$$H_{soffit} = K_s Q_s^2 \tag{4}$$

$$H_{vent} = K_v Q_v^2 \tag{5}$$

Continuity requires that the flow into the attic must be equal to the flow out of the attic as indicated in (6).

$$Q_{total} = Q_{soffit} + Q_{vent} \tag{6}$$

Since one soffit and the ventilator are in parallel, an equivalent resistance must be calculated before the overall circuit may be solved.

Writing (6) in terms of head loss and resistance rather than flow:

$$\left[\frac{H}{K}\right]^{1/2} = \left[\frac{Hv}{K_v}\right]^{1/2} + \left[\frac{Hs}{K_s}\right]^{1/2} \qquad (7)$$

In order to simplify the model, it is assumed that the ventilator and the down wind soffit each see the same pressure differential so that H_v, H_s and H are the same. Equation (7) then simplifies to:

$$\left[\frac{1}{K}\right]^{1/2} = \left[\frac{1}{K_v}\right]^{1/2} + \left[\frac{1}{K_s}\right]^{1/2} \qquad (8)$$

and can be easily rearranged to represent a single resistance equivalent to the original two parallel resistances as shown in equation (9).

$$K = \left[\frac{K_v^{1/2}\, K_s^{1/2}}{K_v^{1/2} + K_s^{1/2}}\right]^2 \qquad (9)$$

The overall path resistance is then the sum of the soffit resistance and the equivalent of the soffit/ventilator parallel path. If it is assumed that the resistance of the soffit is not dependent on whether the flow is into or out of the attic, the overall head loss is given by (10).

$$H = \left[K_s + \left[\frac{K_v^{1/2}\, K_s^{1/2}}{K_v^{1/2} + K_s^{1/2}}\right]^2\right] Q^2 \qquad (10)$$

Or, since the primary interest is the flow rate through the attic space, equation (10) may be rewritten to solve for flow as a function of head loss as indicated by equation (11).

$$Q = \left[\frac{H}{K_s + \left[\dfrac{K_v^{1/2}\ K_s^{1/2}}{K_v^{1/2} + K_s^{1/2}} \right]^2} \right]^{1/2} \qquad (11)$$

In order to predict the net flow through the attic space, the relative resistance of each flow path and the pressure distribution around the attic must be determined.

Since the primary interest is gauging the effects of the attic ventilator, some assumptions concerning the flow path resistance may be made and the net change in exchange rate with the ventilator calculated. The turbine ventilator installed in the test house had a 305 mm diameter base giving an opening area of approximately 72900 mm^2. The soffit installed on each side of the test house was 2.6 m^2 in area with 3875 perforations per square meter. The perforations were produced by putting the soffit through a forming process which did not completely remove material but produced a series of louvre like recesses. Each recess had an open area of approximately 8 mm by 0.5 mm, producing an net open area of approximately 1.5 percent. The total open area in the soffit on one side of the house was 40300 mm^2 or 55 percent of the area of the turbine ventilator base. Assuming that the soffit and turbine ventilator act like sharp edged holes, the relative flow resistance can be estimated by considering the free area. Given that the flow resistance is proportional to 1/area^2, the soffit resistance may be estimated as four times the turbine resistance.

When the ventilator is not present, the flow through the attic becomes approximately;

$$Q_{no\ vent} = \left[\frac{H}{2K_s} \right]^{1/2} \tag{12}$$

While inclusion of the ventilator leads to;

$$Q_{vent} = \frac{H^{1/2}}{\left[K_s \left[1 + \frac{1}{9} \right] \right]^{1/2}} \tag{13}$$

The ratio of equation (13) to equation (12) shows the estimated increase in ventilation rate expected through the use of a turbine ventilator, of the type described.

$$\frac{Q_{vent}}{Q_{no\ vent}} = \frac{\dfrac{H^{1/2}}{\left[K_s \left[1 + \frac{1}{9} \right] \right]^{1/2}}}{\left[\dfrac{H}{2K_s} \right]^{1/2}}$$

$$\frac{Q_{vent}}{Q_{no\ vent}} = 1.34$$

Note that although the ventilation area in the attic has been doubled, the model predicts an increase in exchange rate of 34 percent. Extrapolation of the model to larger and larger exit areas shows that, eventually, an increase in exit area will no longer produce a measurable change in ventilation rate. As the size of the exit is increased, the ventilation rate becomes more and more limited by the resistance of the inlet soffit.